# THUNDERSTORM FORECASTING

F. A. Berry, Jr.

and

J. Maginnis



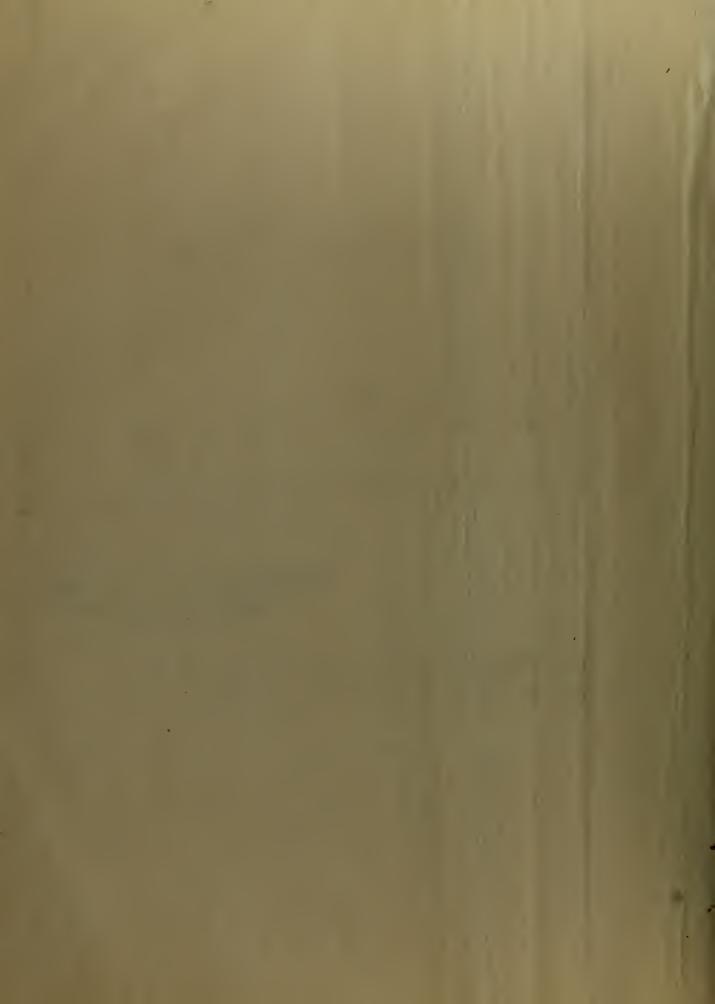








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Thesis by

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Lieutenant F. A. Berry, jr., U. S. Mavy

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Lieutenant J. Majinnis, U. S. Mavy

In pirtial fulfillment of the requirements for the degree of Master of Science in Meteorology

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C lifornia Institute of Technology
Pasidena, California

1937

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In this paper no thempt has been and to present statistical study of thunderstores but rather, by a study of individual cases, to arrive at a mais on which the forecasting of succeptaneous may be precised from the synoptic situation combined with the upper air soundings, if available. Since thunderstorms may be the result of one or core factors it as decided to arrange a classification, depending upon the ortical rate of ctors, as follows:

- 1. Air mass thunderstorm.
- a. Convective.
  - b. Oro raphical.
- 3. Front 1 thunderstorm.
  - . Cold front.
  - b. Warm front.
- 3. Fre-frontal thunderstorm due to a convergent field of motion.

efore oin into a stailed discussion of the types of thunderstore it as considered divisible to surgarize diefly the processes of their eneration. First of all overy thunderstorm, should him assor front 1, is produced by isolated menutrative convection, the result of a unstable

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condition in the air mass, wherein the potential over y due to the initial distribution of temperature and motiture as been converted into the kinetic energy of the rising column.

The unstable conditions required may be developed by he tim of the surfice Lyers of the air, or by listing the entire mass over an orographic obstruction or frontal surfice; providing the air mass is initially conditionally unstable. Nectors which may contribute to the development of unstable conditions, but which, in the light of present dy knowledge cannot be considered as primary causes of instablisty, are convergent fields of motion and registion from his blevel cloud systems.

To determine if conditions exist which may led to the formation of a thursderstorm the aero, man sounding should be plotted on a methodological chart, preferably an adipactic or similar chart, hi ce the trainic representation of thursderstorm conditions in most readily recognizable there. If the sounding has been plotted the lifting condensation lovel should be determined. To exclain; an air particle, not a turated, which is lifted will follow the dry adiabatic passing through the surface point to its a turation point, the intersection of that particular adiabatic with the saturated specific hundridity like corresponding to the specific hundridity of the surface particle. This joint, the LCL, having been reached the particle will follow the moist adiabatic as it as and further. Forever, as long as the rising

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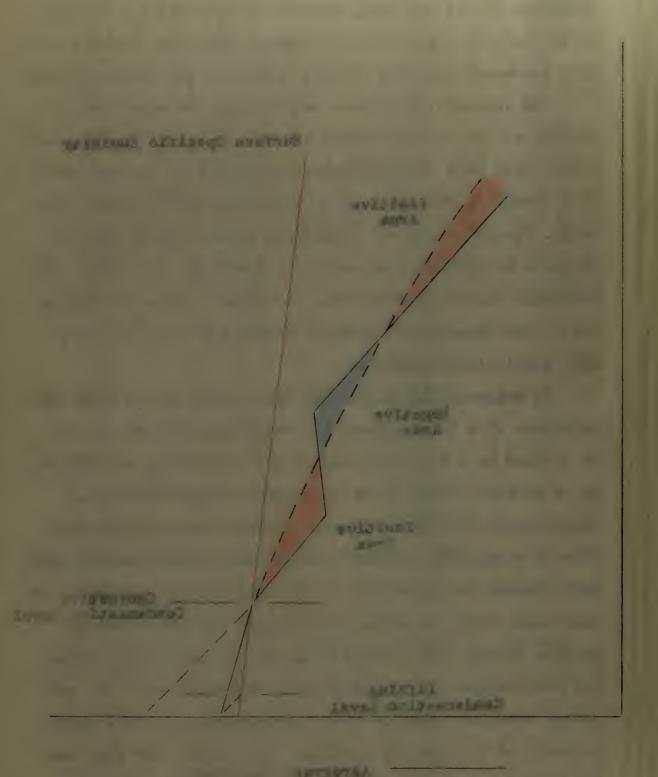
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DEVELOPED AN ADDRESS OF THE PARTY NAMED IN COLUMN TWO NAMED AND DESCRIPTION OF PERSONS ASSESSED AND ADDRESS OF THE OWNER, WHEN PERSON NAMED IN went where decours the amount of the particle has OWNER, PRINCIPLE AND DRIVE DESCRIPTIONS AND ADDRESS OF THE PERSONS ASSESSMENT OF Currier memoral set former his manufactor by equations in account, Surface Specific Humidity LETTER BUT THE PARTY HAVE THE WATER STANCESTON STATE OF THE PERSON . IN CHARLES AND RESIDENCE AND ADDRESS OF THE PARTY AND PERSONS ASSESSED. Positive Area SAME SAME AND ASSESSMENT PROPERTY. Volley and har Complete Street and the Contract of the Line of the Contract o The results of the last of the second of the last of t married the sales of the late of the sales are deputied to public cases in it was manufacture was particle. Meg tive Area THE RESIDENCE OF THE LABOR. THE RESIDENCE THE REAL PROPERTY. The Louisian Lines, the Lines THE REAL PROPERTY AND ADDRESS OF THE PARTY ADDRESS OF THE PARTY AND ADD Positive Tea Tea Convect's with live to be district the Condensati AND ANY OLD PERSONS ASSESSED AND ADDRESS. an area cassing it has all state to the party money are Lifting Condensation Level - Control by Suppose to what that there produced and more

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particls is cooler than the surrounding air t the sine level energy must be applied to further its ascent. Then the s-STILL STREET, cent curve crosses the sounding curve and the particle becomes warmer, and hence less dense, than its aurroundings no further mechanical force is necessary to maintain its ascent, AND THE THE PERSON NAMED IN COLUMN TWO free convection will ensue. As len, as the particle is sarm-CALLER THAT IS THE PARTY OF STREET er than its surroundings its ascent will continue to be accthe particular street of the same of the particular street, ellerated. The areas on the adiabatic chart enclosed between the party will improve the land the the aero riph bounding and the ascent curve of the particle re roughly proportional to the resistance against lifting, at each point where the rising particle is cooler than the surrounding air, or to the amount of enery available for STREET, OF THE PROPERTY OF REAL PROPERTY. ccelerating the particle tech wint here it is warmer then its surroundin s.

In addition to the LCL the convective condensation level should be determined. To explain; this point is the interaction of the naturation specific hundridity line, for the surface point, with the agree of the curve. From this point the intersecting dry adiabatic followed down to the surface level

in to the condendation level. Tree convection will continue on from this point if the particle is very here warmer than its surroundings.

ative are a represent acc levations, not velocities, and the reform if a particle has been accelerated up and during a

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chart, and ther enter a resistant stratum its upward v locity will be decellerated, not necessarily halted. No ever, it may be assumed that the upward prograss of the particle will be coupl toly halted when the resistant stratum, as represented by the negative area on the chart, is approximately equal to the accelerating areatm, as represented by the posttive area, which has given the particle its initial inputus; this point, where the negative area in a re-check equality with the positive, will mark the uppermost limit of convection.

In rriving at a decision as to the relative effect of these positive and negative area, it hould be remembered that their accelerations to roduced by difference in donit between the rising particle and the purrounding wir. Tendity is a function of both presour and temperature sines  $C = \frac{P}{RT}$ . From consideration of this familiar equation it is apparent that, for a liven difference in temper ture, the density difference depends only u on the pressures, which must be equal. Thus is aren of a liven size at an altitude where the pressure is 500 millibar indicates only one half the accoloration which the same sized read and have at an allitude of re the pressure is 1000 millicars. Thus it are of a pricible size rearing ear the surface livel i. a i dication of a more violent hungerstorm than if it appeared t 3000 or 4000 meters. This fact will becore noise apparent after an examination of the thunderThe property of the party of the party of the Attention o

to preside any many or a second property of the supplemental and property of the party will be to william the said -the law of the law of VALUE AND THE PARTY OF THE PART results where the risk is no recording their the configuration of the particular P. T. To a continue of unit and the same permission and in sometimes with a contract the second and the ANY OF THE PARTY O of the Party of the later or name of the Party of the OF REAL PROPERTY AND PERSONS AND PERSONS ASSESSED. many of the court was not the first many regions our time now required the same of the same NAME AND ADDRESS OF TAXABLE PARTY AND ADDRESS OF TAXABLE PARTY. The state of the s and offer form of the company of the well and the subject to the party of the par

storm examples which follow.

level, either due to lifting or surface heating, clouds will be formed. Although not definitely established, it is believed that the vater druplets in the cloud will not form relations until convection has reached the ice crystal revel, the p it where the rising particle crosses the zero isotherm. There, ice crystals mixing with, or raining through, the later dro lets serve as nuclei for the formation of rainare a. It may be assumed that precipitation will out begin until the top of the cloud has reached the ice crystal level.

another assumation is that the potential predient necestry for the development of thurderstorms is established
by the splitting of reindress as a result of violent scendin currents ithis the cloud. The minimum value of the uperd velocity necess ry to produce this effect is company
assumed to be 8 meters per second.

Included here is a series of hypothetical situations
that various degrees of instability are represented. ...c.

Till produce different the nomena, randing from the formation of a cumulum cloud without rain to the formation of

violent thanders tors accompanied by hail. By means of

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Type # 1. This situation would result in the formation of cumulus clouds without precipitation since the positive a area is approximately equal to the negative and the ICL is above the point where convection ceases.

Type # 2. This situation would result in the formation of cumulus with showers since the convections extend above the ICL. However, a thunderstorm would not be expected since the vertical velocity attained by the rising air would not be sufficently strong, as shown by the fict that the area of available energy is small.

Type # 3. This situation would result in the formation of a thunder torm since the convections extend above the ICL and the vertical velocity trained by the rising air would be sufficently strong to disrupt the raindreps and establish the potential predient required for an electrical display.

However, hail would not be expected since the area of positive area above the ICL is scall.

Type # 4. This situation would result in the formation of a light thunderstorm, accompanied by hail, since the convections extend well above the ICL and the vertical velocity, while reaching appreciable value at the ICL, will continue to be accelerated for a considerable distance above that point. This is indicated by the large positive area. This situation is common in winter months in southward moving polar maritime masses.

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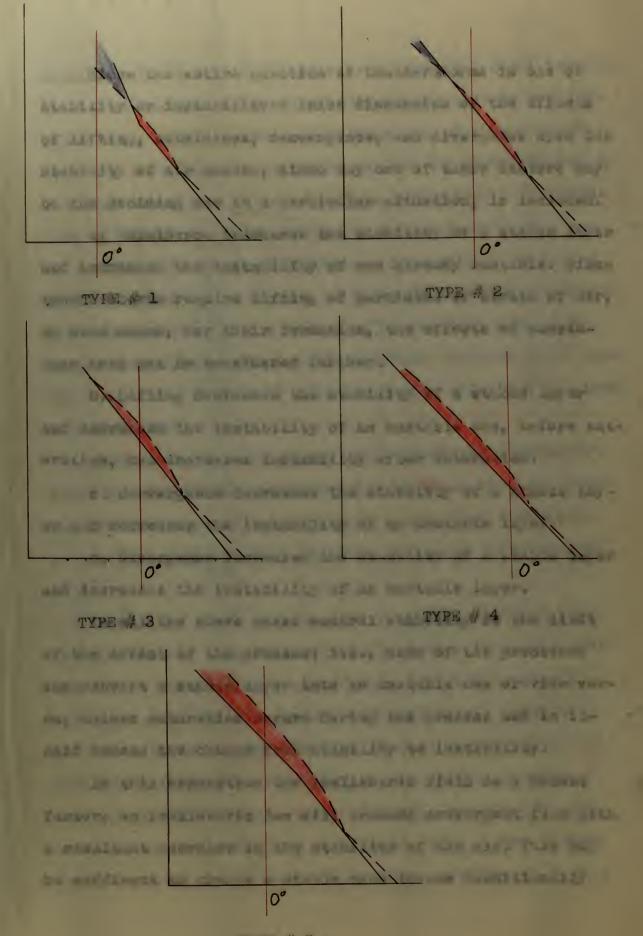
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Type # 5. This situation would result in the formation of a violent thunderstorm accompanied by hail, since the vertical velocities attained prior to reaching the ICL would be exceedingly large as indicated by the large positive area below that point. Above the ICL there is further increasing positive area which would increase the accelerations far above that point.

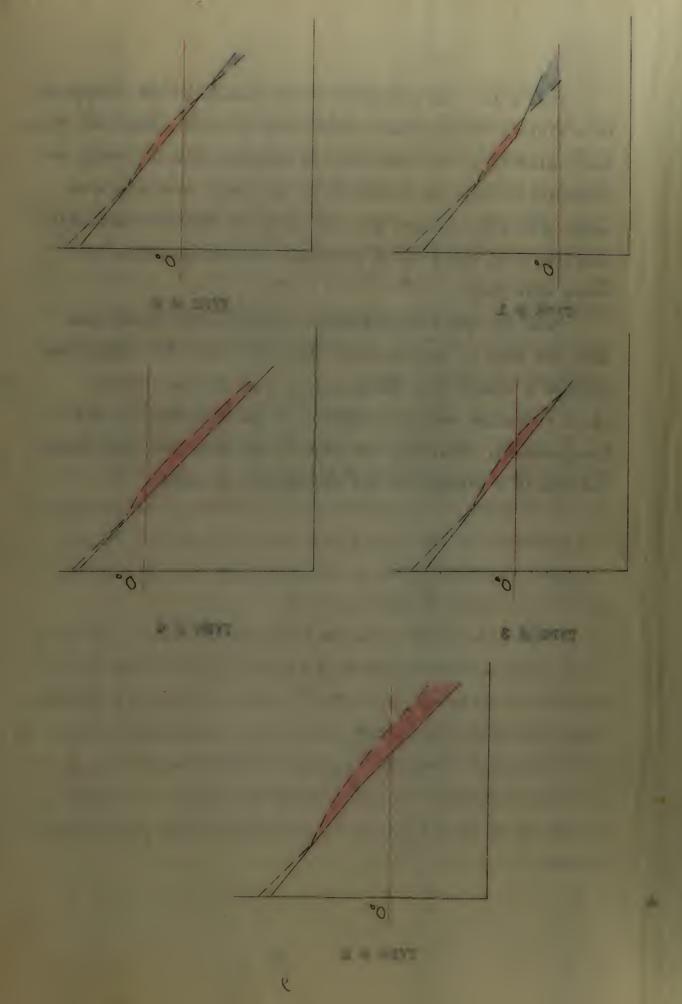
From the above hypothetical situations is would seem that the size of the positive area below the ICL determines whether a shower or a thunderstorm will develop from a liven situation and is a measure of the intensity of the thunderstorm. Similarly the size of the positive area above the ICL is a measure of the probability of hail.

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Since the entire quistion of thunder torms is one of stability or instability a brief discussion of the effects of lifting, subsidence, conver ence, and divergence upon the stability of air masses, since any one of these factors may be the deciding one in a particular situation, is included.

a. . ubsidence increases the stability of a stable layer and increases the instability of one already unstable. Since thunderstorms require lifting of particles or strate of fr, by some means, for their formation, the effects of subsidence not be considered further.

b. Lifting decreases the stability of an unstable one, before saturation, but increases instability liter saturation.

- er ad decreases the instability of an unstable layer.
- d. Divergence increases the stability of a stable layer and increases the instability of an unstable layer.

In all the above cases neutral stability is the limit of the effect of the process; i.e., none of the processe can convert a stable layer into an unstable one or vice versu, unless saturation occurs during the process and in itself causes the change from stability to instability.

In this connection the is llob ric field is a potent factor, an isallob ric low will produce convergent il a with a resultant decrease in the stability of the air. This hay be sufficent to change at the mass to one conditionally

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unstable with resultant thunderstorm activity. Thus, issuedtion of an aerograph sounding without reference to the dynoptic chart might indicate no probability of thund retorms.

Notever, the change in structur of the air mass produced by
a strong conver and field of motion, indicated by the presence of strong negative tend noise on the weather map, may
be sufficent to produce conditional instability. As for as
is known there is at present no means of making a quantitative determination of the effect of convergence upon at bility; therefore estimation of its effect must be based upon
experience. An example of this particular situation is given
in section one.

Conversely an isellobaric high, producing a divergent flow, may stabilize a conditionally unstable mass and prevent the formation of thunc raterms atthough an inspection of the erograph sounding may have indicated their probability.

thou h cornorly associated ith subsidence, is always present in air everyanning a warm front, except n ar a well developed low pressure center, and also may be present in air being lifted ore praphically. In case of constitutally unstable air which is saturated by the lifting process, from a lor ore graphical, this divergent flow ands to the instability produced. Thus air flowin from a warm sector, in which there are not tive tendencie, overcating a warm

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front is subjected successively to converge ce, litting to reduce instablished.

nother factor which must be considered in cating time the changes in the structure of an air ras. It r the erorath sounding has been rade is the day lo ment of large so le turbulence du to a lar e vertical velocity prodent. Turbulence t nds to produce a state of neutr 1 equilibrur, eith r for the dry or saturated state, depending u on the noint of soleture recent. This reduces the relative humidity of the surface layer and thus raises the CCL and the m xi m temper tire required for fr a convection. In duition, ir having a raximum of mointure in the up or layers, n and ct f turb lence, b in subjected to lift all be wide more a able wince the urper 1 yers would reich sturation befor the lower and thereafter cool at the moi tad-IN THE PLAN WILL COMPARED TO BUT OF ALL MAN DESIGNATION i tic rate while the lover levels would still be cooling First a greatedpe of the operate souther pleasure, and at the steeper dry diab tic r te. On the other hand, ev n thou ha sounding may show the presence of a large investion in suspentialor st ble l yer which will block co vective activity, turb-THE PARK SE ASSESSED AT LAST STREET OF LESS OWNERS OF THE PARK OF ulence may be sufficent to It r this structure and ermit ONC DIS RESULT OF THEIR PROPERTY AND NOT THE REAL PROPERTY. thunderstorm develorment which would not be anticipated it this f ctor were not considered. NAME AND ADDRESS OF THE PARTY OF PERSONS ASSESSED. THE PERSON OF

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The choice of specific humidity of the point to be raised by convection from insolational he ting is, of course, of considerable importance. Normally, on days when convective ctivity is going to occur, the early morning hours will be clear and a surface inversion developed by nocturnal radiation. In this case it is customary to take an average of the specific humidities of all points below the top of the inversion and use this value to the actual specific humidity of the point to be raised. This is particularly, true if any vince is expected during the day which will mix the lower layers.

The exposure of the station aust also be taken into consideration; thus if the flow of air as from a water surface, such as a coastal or lake station, no decrease in the surface specific numidity need be enticipated.

In forecasting the convective type of air mas, thunderstorm a knowledge of the probable maximum tem, enture for the day and the rate of the nie of temperature during the day is essential.

The rate of change of temperature of the currace depends upon the amount of insolation received and the soil constants, The first is practically constant throughout the pear for the same sky conditions but the latter vary widely from place to place, depending upon the mount of soil cover, the character of the soil and the amount of moisture present in the soil. Since there are too variable and difficult to ascertain, the

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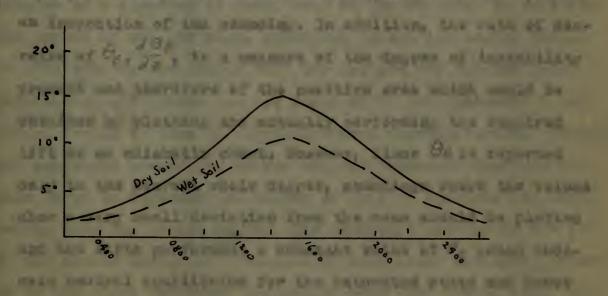
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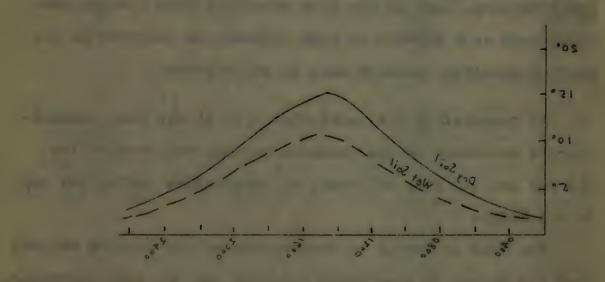
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use of equations to determine r tes of change or tem erature does not yield results worthy of the mount of loor lavel-ved. In tead, for this purpose alural tem erature curves for each month of the pear, under the different sky and surface conditions, should prove to be of considerable as istance. These curves can be made up for clear, closely, partly cloudy days, and dry and wet soil. From thermograph records of mast years, the amplitude of the curve and the variation from the mean for each hour or two hours obtained. These values can then be plotted on an arbitrary scale of temperature versus time and the general shape of the curve obtained. For example:



heedless to say, the curves for any two days under similar conditions will very probably have different absolute values but the general shape of the curves should be the same. The forecaster, knowing the amplitude of his curve, can apply this to his minimum temperature and determine whether the requires temperature for convections can be reached.

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Normal was tilly mover all soundings have been played and In situations where lifting of an appreciable lag r or little defended the country of the second will be a factor in thunderstorm development the equivalent OUT STREET, NO THE PERSON NAMED AND POST OF THE PERSON NAMED IN potential temperature,  $\theta_{E}$ , of each salient point, to ether with the lift required to saturate each, is extremely valand the real to he william made out out the free speciality uable to the forecaster in his examination of the sounding Lie procedure impressor appresionate de lisergous la a il available. Since values of  $heta_{\mathcal{E}}$ , decreasing with increasing altitude, indicate potential instability, and the indicated lifts give the lift required to saturate a given stratum, the forecaster, after sufficent practice, can determine how much lift is required to release the conditional instability of the air mass in question, the thickness of the unstable layer, and the point where free convection will start, from the section is used, but it if the real where the an inspection of the sounding. In addition, the rate of decrease of  $\theta_{\varepsilon}$ ,  $\frac{d\theta_{\varepsilon}}{dz}$ , is a measure of the degree of instability present and therefore of the positive area which would be obtained by plotting and actually performing the required lift on an adiabatic chart. However, since  $heta_{E}$  is reported and among the names of the only to the nearest whole degree, soundings where the values sho a very small deviation from the mean should be plotted and the lifts performed; constant value of  $heta_{\it E}$  would indicate neutral equilibrium for the saturated state and hence that a thunderstorm would be impossible since no vertical accelerations outd be developed. In example of this is iven in warm front situation 1; the sounding shows a const at value of  $\theta_{E}$ , 339°, from the surface up to 2.80 meters. However, actually orking it out on an adiabatic chart sho s that a slight dayr e of conditional instability does exist.

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Throughout this paper all soundings have been plotted and the lifts actually performed on an idiabatic chart. Since it is difficult to conceive of lifting taking place in the atmosphere situated divergence at some level, the lifts have been performed ith respect to the altitude scale and not the pressure of letting procedure introduces approximately 8 divergence is a list of one kilometer, which is considered to be conservative. However this is a very tedious process and should not, except in border line cases, be necessary after the processor in become facility with the upper  $\Theta_E$  and lift.

#### AIR MADE SYMBOLE

In the following examples the customer, method of classification of air masses is used, such as Tp, rc, etc. In addition the symbol of any air case, returning toward its nource region in preceeded by the letter "H"; for example are denoted polar continental air, which are not remained in low latitudes a sufficient length of time to assume tropical characteristics, returning northward toward its source region. Subscript namerals are also added to indicate the number of dups an air mass has been moving from its source region. The subscript entered to the laft of the symbol indicates a trajectory over water surfaces, entered to the right indicates trajectory over land areas, e.g., in ifies polar pacific air one day from its source, with a subscript designates travel for a consider ble period of time, sufficient that the fir has lost its original characteristics but he not assumed the char-

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In the following the property of the property of the state of the stat

acteristics of air typical of the region over which it is moving, e.g., okpc signifies polar continental air returning northward after a trajectory over later of several days duration but not sufficently long for complete assumption of Tg or Ta character.

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#### SECTION ONE

#### AIR MASS THUNDERSTORMS

Under this category are included those thanderstorms occurring in the absence of frontal activity; those caused by surface heating and orographical lifting. This type is of course more frequent in the summer months. They may occur in almost every type of air mass, but are observed most frequently in T<sub>o</sub> and Ta masses due to the typical structure of conditional instability and large moisture content inherent in them. however, they are observed on the Pacific Coast in winter in fresh Pp air; illustrations of this type are included in this section.

In the foregoin section the general mechanics of thund retorm formation have been discussed, and mention made of
the f ctors which, within the forec st period, may alter the
structure of the air from that shown by the original erograph curve to a structure, either more or less f vorable to
thunderstorm production. In addition, a classification with
respect to the type of phenomenon to be expected from a given
structure, once convections were established, was given.

In this section several examples of air mass thundertorms are presented, with a brief description of what appear to be the sulient flatures of each. Unfortunately, in the reports, the relative intensity of the thunderstorm and the typ- and amount of precipitation are frequently not given.
There possible, this has been estimated by consideration of

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of the precipitation reports on the weather maps. However, these can by no means be considered conclusive, since by its very nature thunderstorm precipitation is sporadic; and the reports received from two closely adjoining stations may be widely variant.

#### EXAMPLE # 1.

Pensacola, Florida. 28 April, 1936.

This is type # 3, air mass thunderstorm situation.

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First, consideration of the synoptic chart shows the forecaster the air mass or masses with which he is dealing. In this case the synoptic chart shows that, during the forecast period, he will be dealing with but one air mass, characterized as R<sub>3</sub>Pc<sub>1</sub>, approaching Tg, but emphatically not a true Tg air mass as is clearly borne out by the aerograph sounding which shows the stratified moisture distribution typical of old Pc in this region. Incidentally this stratification gives a very much more violent reaction when lifted, convectively or frontally, than pure Tg with its more symmetrical moisture gradient.

The explanation of the choice of the specific humidity to be used for the rising particle has been given above; in this case, due to the location of the station on the gulf of Mexico where the surface levels are assured an ever fresh sup by of moisture, with on-shore winds, the actual specific humidity, it grams per kilogram, of the surface point is chosen.

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Inspection of the adiabatic chart shows the LCL at 1008 millibars, 140 meters. If the moist adiabatic is followed up from this point it will show a small negative, resistant, area to 900 millibars. Unless there is some state factor, or an ero raphic obstruction, to change the atructure of the air or to further mechanically lift it no convections from lifting would be expected to take place. In this case no such conditions were present so attention is given to the CCL.

Inspection shows the CCL at 952 millibars, 600 meters; the dry adiabatic followed from here to the surface point shows that a maximum temperature of 25.60 C. is required to establish free convections from insolation 1 heating. An exmination of the clurnal temperature curves for this at tion shows that such a temperature is not excessive for the date.

Since free convection is probability return to the CCL and follow the moist adiabatic up from that point. It is seen that everywhere the aerograph curve is colder than the path followed by a surface particle moving up the moist adiabatic from the CCL; in short, that there is positive area at all points which would accelerate a particle for a distance of 3900 meters from the CCL to the ICL, and for some distance, which, one to the termination of the aerograph sounding, cannot be determined, beyond that point.

thunder term should be predicted for the station.

Since the ICL is very high, 582 millibers, 4500 meters, and the structure above that point cannot be completely pictured, it would be safer to predict only rain with it, hail probably

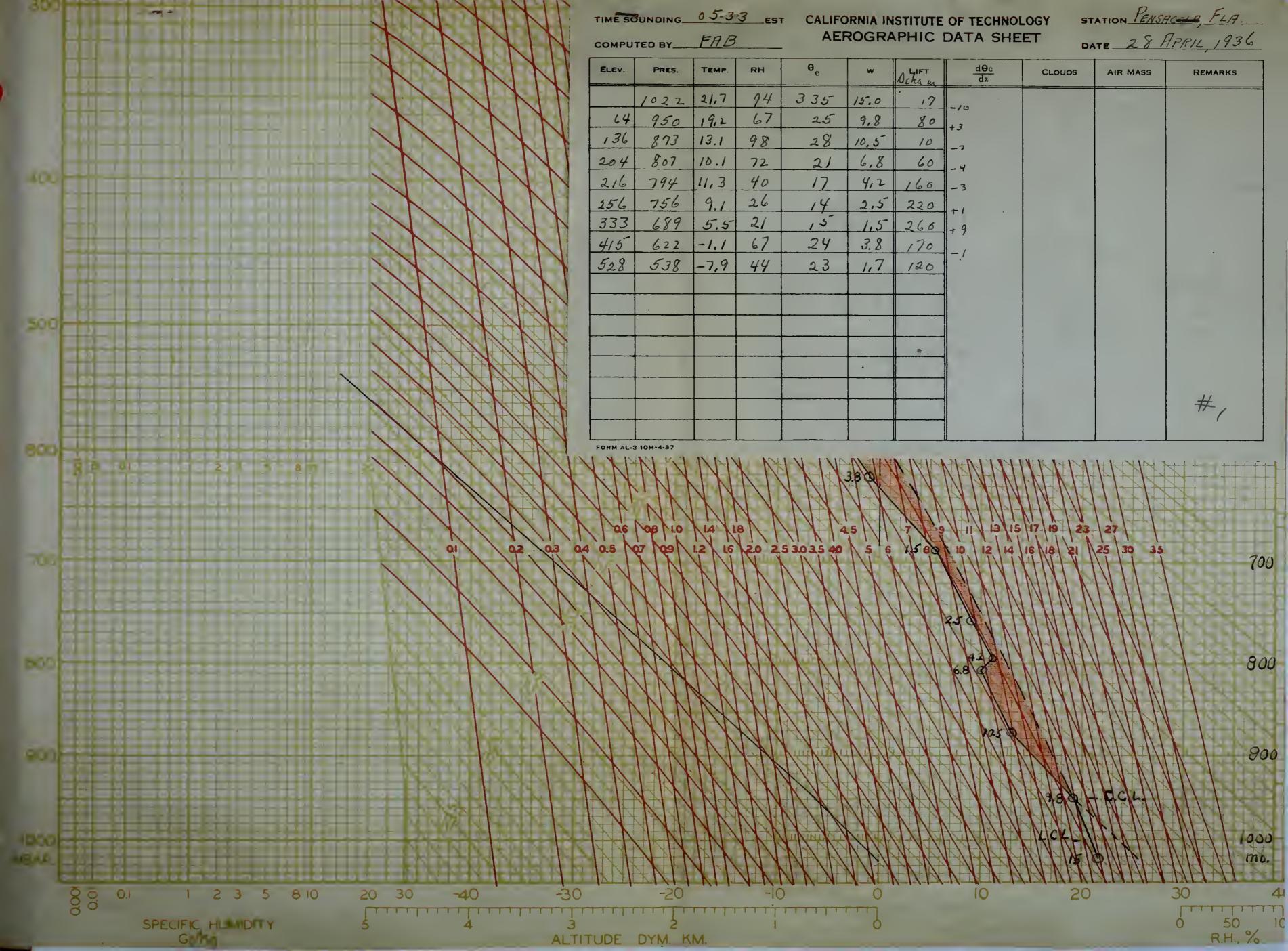
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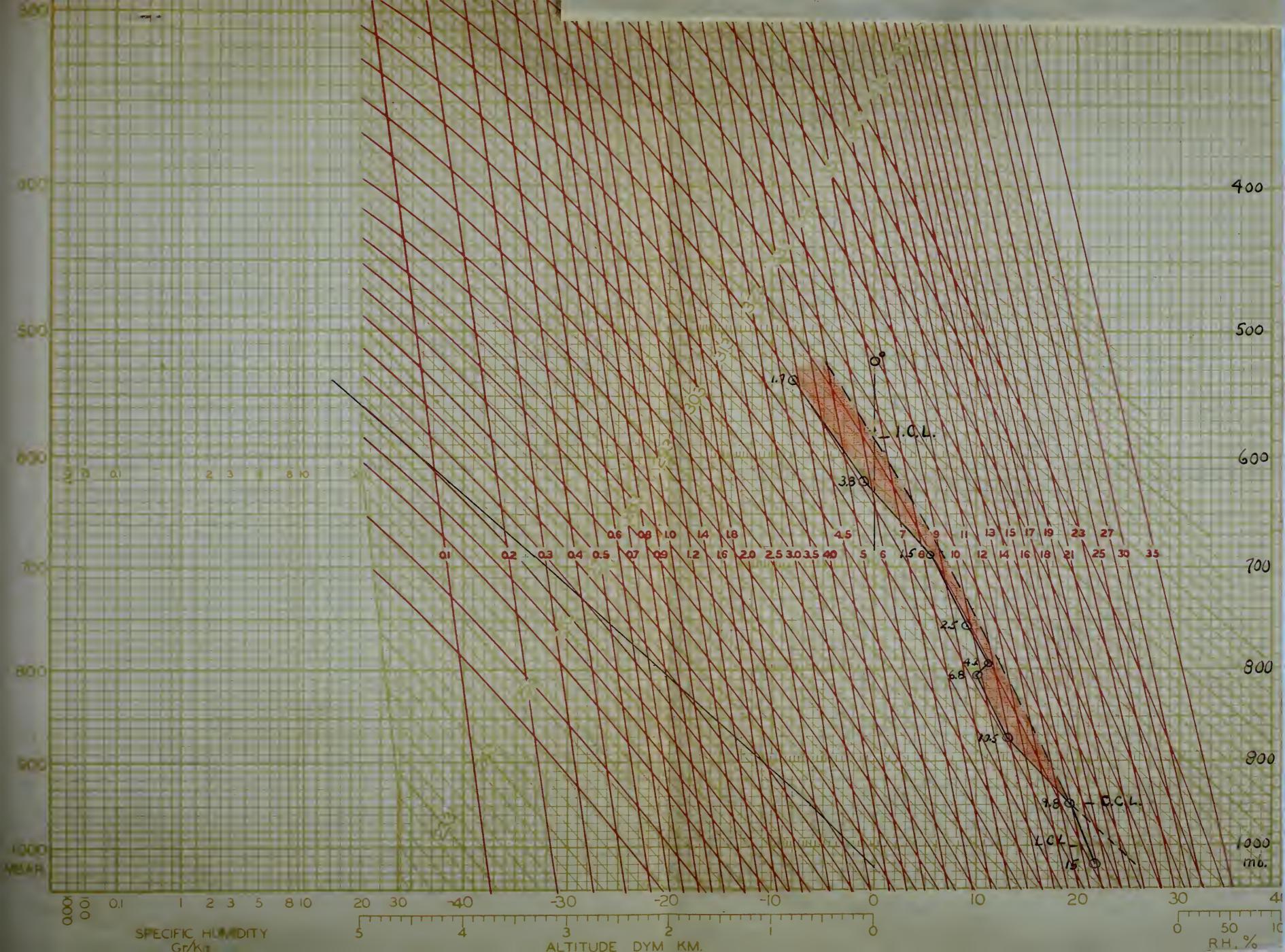
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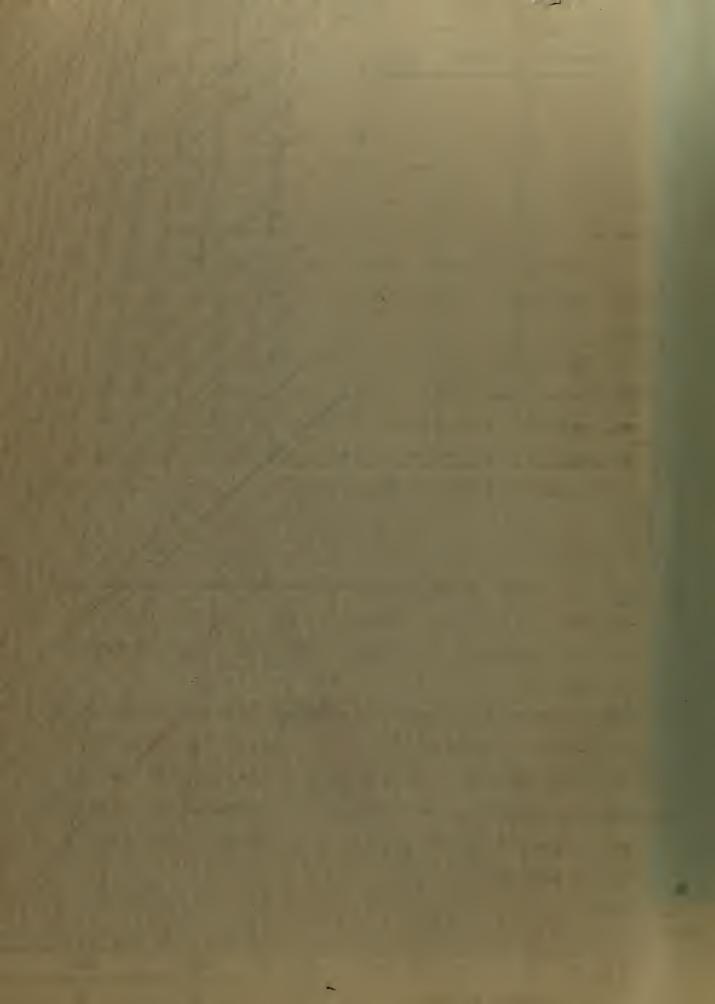
condition and not been placed in the statement of the statement base where we are selfthan the statement of the statement o

would not reach the surface. The time at which convections would reach the condensation level could be predicted quite accurately by use of the diurnal temperature curves and the adiabatic chart, but predicting the hour at which the thunderstorm would break, or how long it would last, is a fine point which will not be attempted here.

A thunderstorm of considerable intensity accompanied by 1".12 of rain, and justs of 35 knots, occurred at the station at 1830.







Pensacola, Florida. 21 May, 1936.

This is type . 3, air mass thunderstorm situation.

as in case one, first consideration is given to the synoptic chart to determine the air mass with which the forecaster is dealin. In this case the air mass is Tg.

The actual precific humidity of the surface point, 15.5 rus per kilogram, is chosen to determine the LCL and the CCL.

The LCL is found to be at 1007 millibars, 130 meters.

Here, wain, mechanical lifting to an extent shic can not be realized, or a change in the structure of the air mass, which the synoptic chart shows not to be probable, would be required for convective action from lifting.

The CCL is found to be at 920 millibars, 930 met rs. The dry abiabatic followed from here to the surface point shows that a maximum temp rature of 28° C. is required for free convection to take place. Inspection of the station diurnal temperature curves show that such a temperature is not excessive for the date.

Naturaing to the whiabatic chart and following the moist aniabatic up from the point where it intersects the CCL it is seen that everywhere above that point lies a positive area.

A particle leaving the CCL sould be accelerated for 4170 neters to the ICL and for a distance beyond that point maion can not be estimated.

#### AS & APPLICATION

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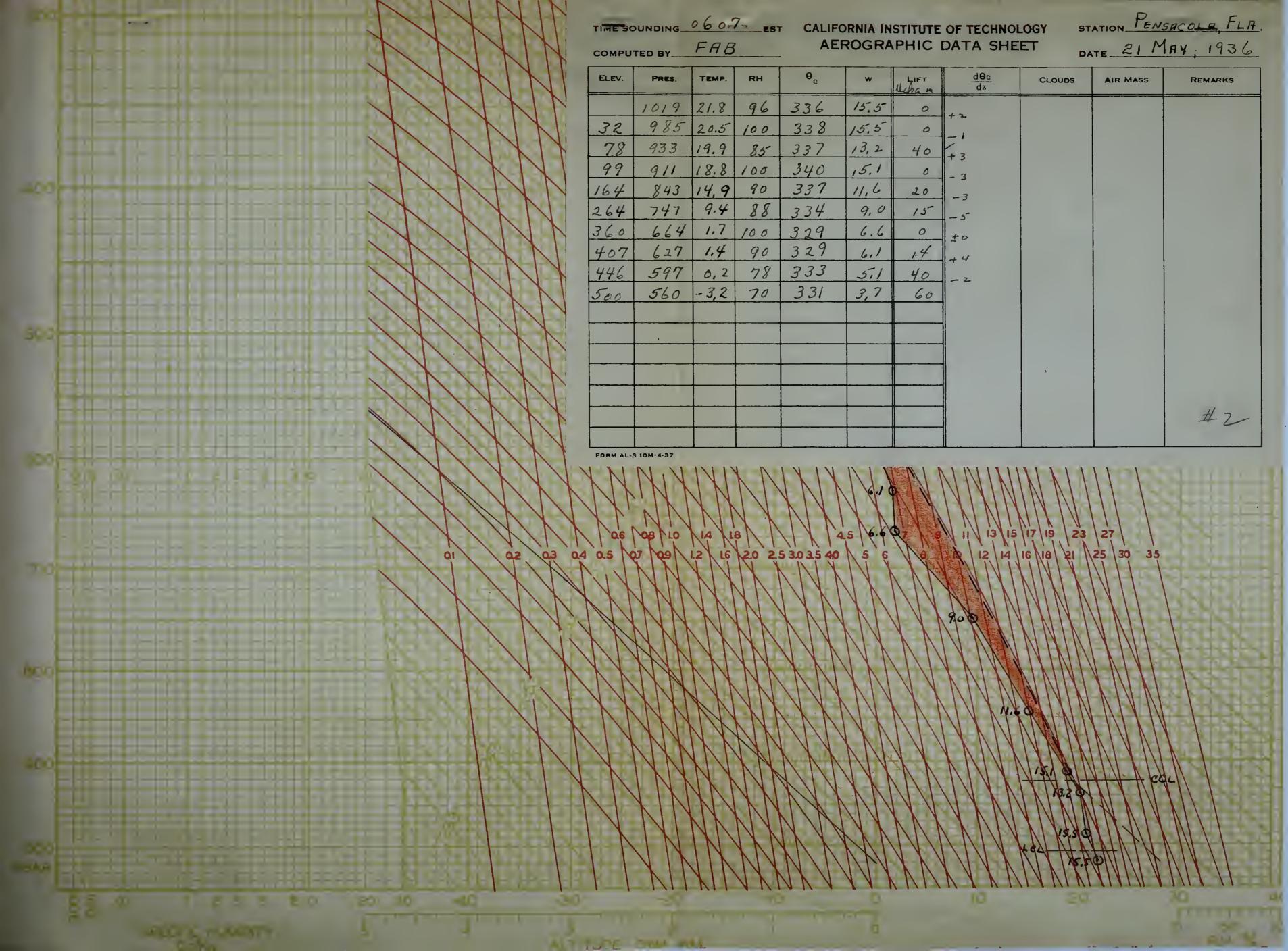
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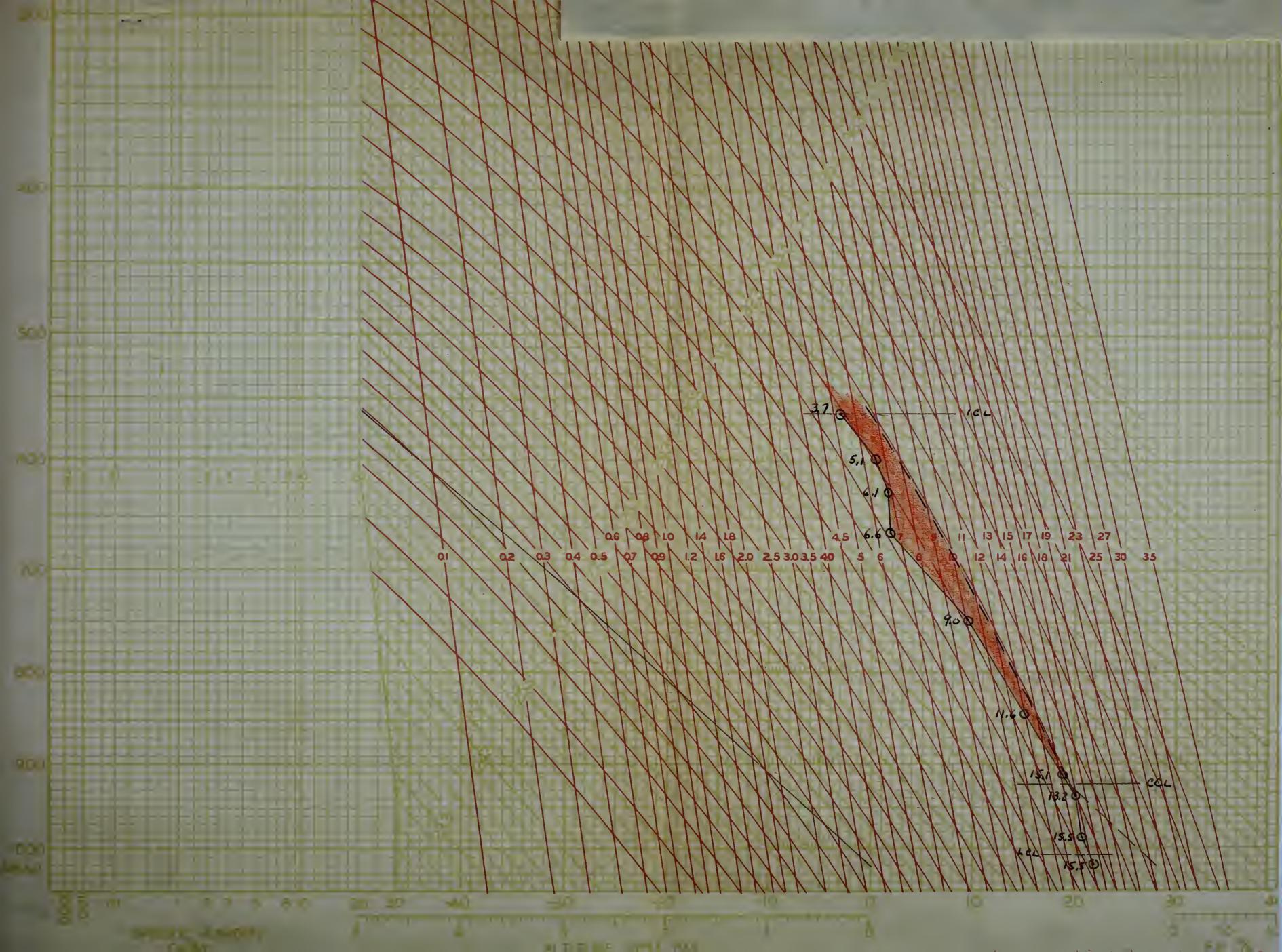
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A thunderstorm should be predicted for the station. Since the ICL is very high, 560 milliours, 5000 meters, and the structure above that point cannot be completely pictured it would be safer to predict only rain to accommany it, hail probably would not reach the surface.

thunderstorm of slight intensity accompanied by a trace of rain, no recorded gusts, occurred at the station at 1700.







## EXAMPLE # 3.

Pensacola, Florida. 21 August, 1936.

This is type # 3, air mass thunderstorm situation.

The synoptic chart indicates that the forecaster will deal with but one air mass during the forecast period, Tg.

In this case, due to the small temperature inversion, which should be wiped out shortly after the sun rises, the mean of the actual specific humidities of the first two points, 18.1 grams per kilogram, is chosen as the actual specific humidity of the particle to be lifted.

The LCL is found to be at 962 millibars, 440 meters. Since mechanical lifting in this amount cannot be provided here, attention is turned to the CCL.

The CCL is found to be at 908 millibars, 970 meters.

The maximum temperature of 31°.2 C. found to be required for tree convection is checked on the station diurnal temperature curves and found not excessive for the date.

If the moist adiabatic is followed up from the point where it intersects the CCL it will be found that positive area is present to the top of the curve. A particle leaving the CCL would be accelerated for 4770 m ters to the ICL and for a distance beyond that point which cannot be estimated.

A thunderstorm should be predicted for the station. Since the ICL is very high, 512 millibars, 5740 meters, and the structure above that point cannot be completely pictured, it would be safer to predict only rain to accompany the thun-

#### ALL O LIDERAGE

Panamaria, Flordan. 21 manus, 1930. This is type o 3, air mess then been votes alteration.

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The CCL is found to be at 308 milliours, 978 meters.

The maximum temperature of 31°.2 C. found to be required for from commention is sheeted on the station discretized temperature derives and found not exceeding for the date.

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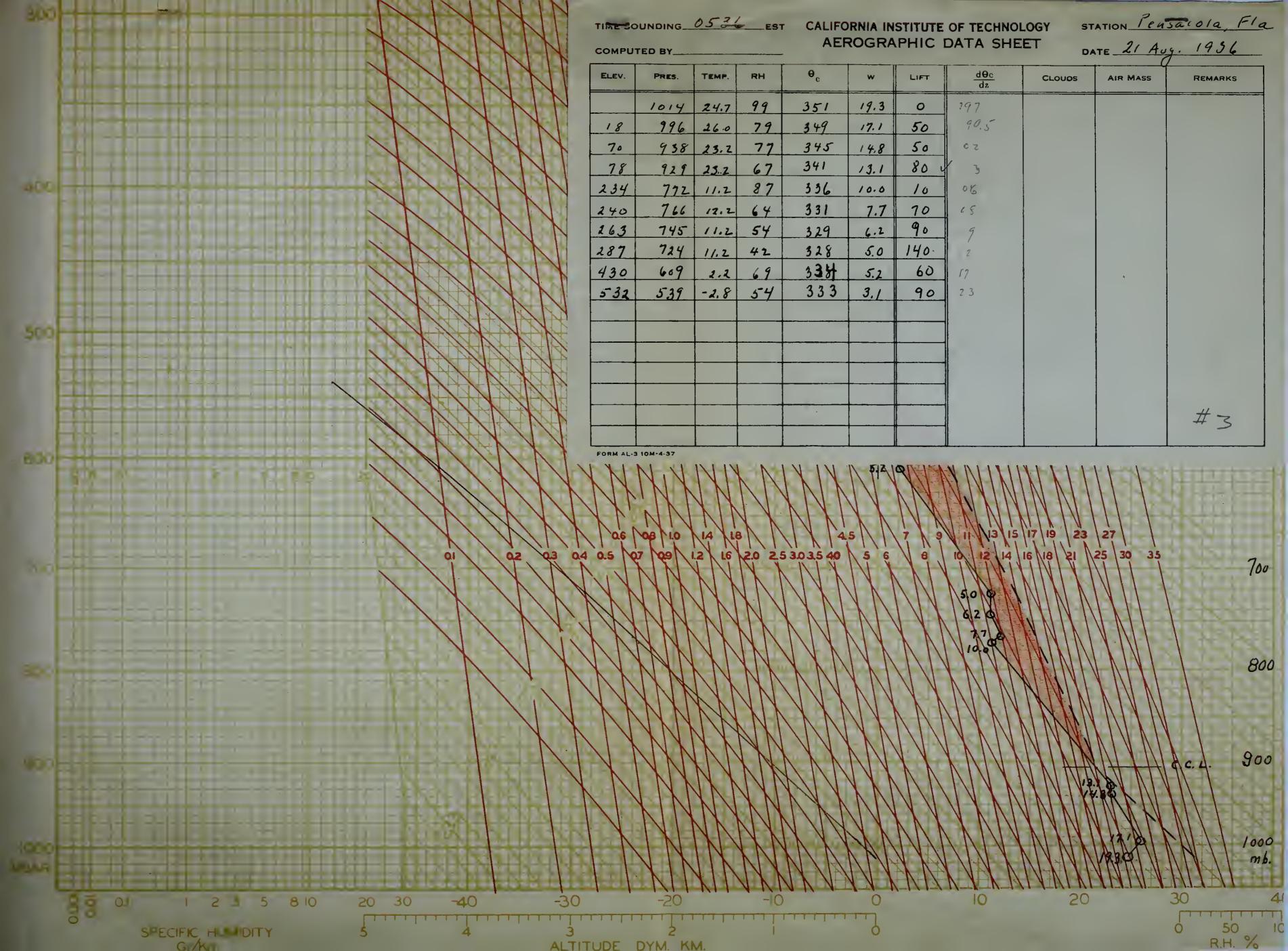
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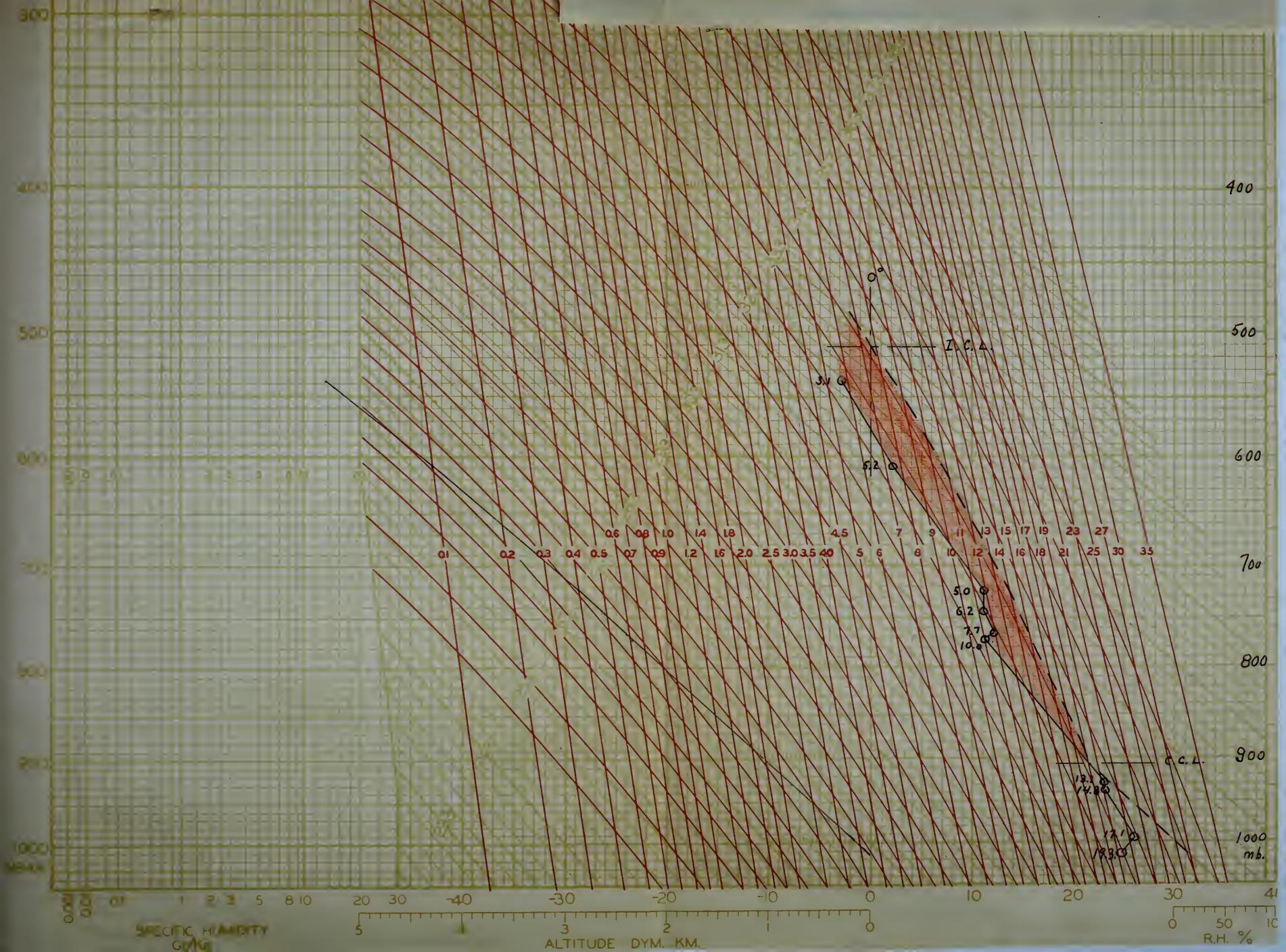
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derstorm, hail probably would not re on the surface.

A thunderstorm of moderate intensity, accompanied by OH.21 of rain, no recorded gusts, occurred at the station at 1800.







Anacostia, Virginia. 10 July, 1936.

This is type # 3, air mass thunderstorm situation.

This and the following case, /5, are introduced to indicate that thunderstorm forecasting is not always certain. From a consideration of the synoptic chart and the adiabatic chart it is not believed that many forecasters would have predicted thunderstorms for this day. Since the possibility of lifting setting off free convection is indicated as impossible, no frontal activity being involved and orographic obstacles lacking sufficent height, the only possibility of thunderstorms would be convection due to insolational heating. A maximum temperature is required for free convection which would not have been anticipated for this day. however, thunderstorms did occur on this day.

The synoptic chart shows that the forecaster will deal with but one air mass during the forecast period, Tg3.

In this case, due to the large temperature inversion, which would have to be wiped out before free convection could arise, the mean of the actual sp cific humidities of the points from the surface to the top of the inversion, 12 rams per kilogram, is chosen as the actual specific humidity of the surface particle to be lifted by convection.

The CCL is found to be at 678 millibars, 3420 meters, and the temperature required for free convection to be 43° C.

This would seem excessive, but since that temperature was

Anacoatla, Virginia. 10 Mary 18:6.

This is type 2, air was tounderstand eitherion.

This is the the following case, 45, are introduced to indicate that the chart tounderstand forecasting is not always owrtain. From a consideration of the appoints that the chart and the admintis chart it is not believed that early forecasters would have predicted trumperstorms for this day. Since the possibility of lifting either off free convection is indicated as impossible, no remain extintly being involved into oral raphic obstants. In the him extincts sufficient trains, are only possibility of them extended a convection to the convection doe to involutional leating. A maximum temperature is required for free convection eater sould not have been suffcipated for the convection eater sould not have been suffcipated for the convection eater and above as the secure on this day. However, tenness.

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In this case, due to the large temperature inversion could exice mould have to be wired out before free convection could arise, the neum of the sound appoints humidities of the points from the surface to the top of the inversion, 12 rese per hillogren, is chosen in the secural specific hashing of the terms average.

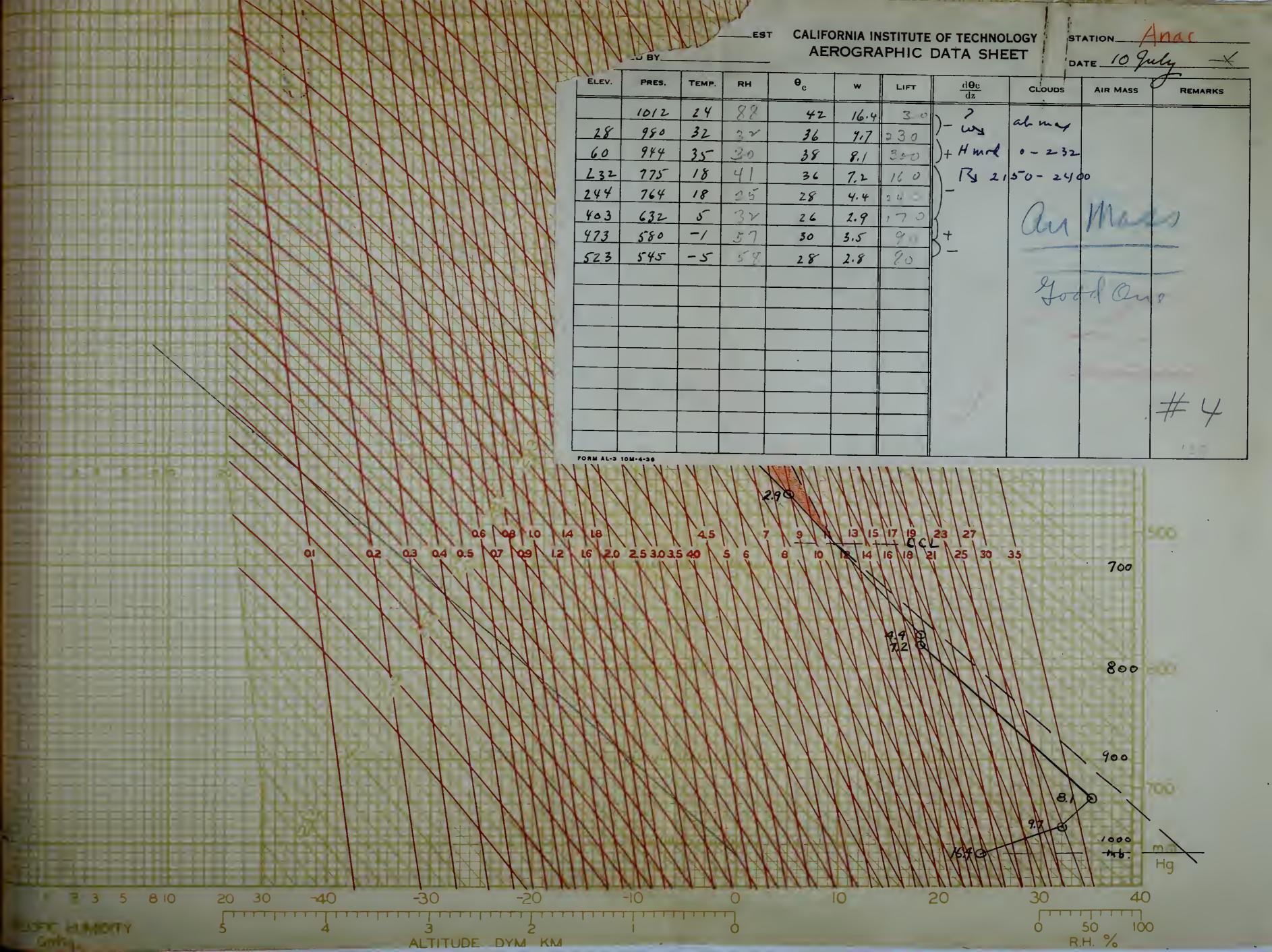
The UGL is found to be at 678 milithers, 3420 meters, and Use temperature required for free convention to be 43° d.

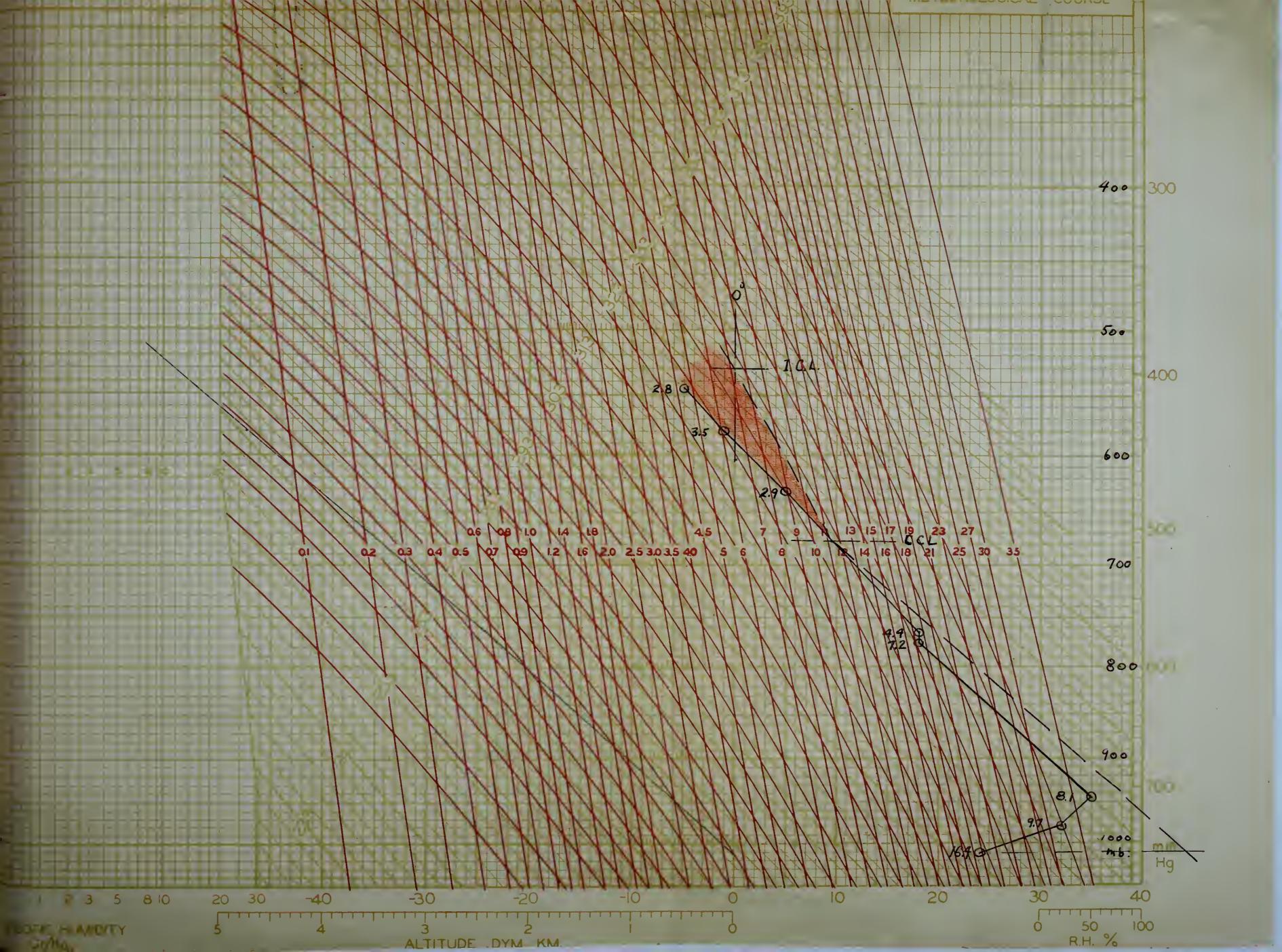
In it would your expective, but since that temperature was

reached on this day it will be followed through on the ac-

Then the CCL is reached by convections due to insolational heating it is found that, following the moist adiabatic up from its intersection with the CCL, everywhere above that point will be positive area. The ICL is very high, 530 millibars, 5400 meters, and the whole structure of the positive area cannot be pictured, but a marticle will be continuously accelerated from the CCL for 2200 meters to the ICL and for some distance beyond that point. A thunderstorm should have been predicted for the station.

A high level thunderstorm of slight intensity occurred over the station at 2100. No record of type or amount of precipitation.







#### EXAMPLE // 5.

Lakehurst, New Jersey. 10 July, 1936.

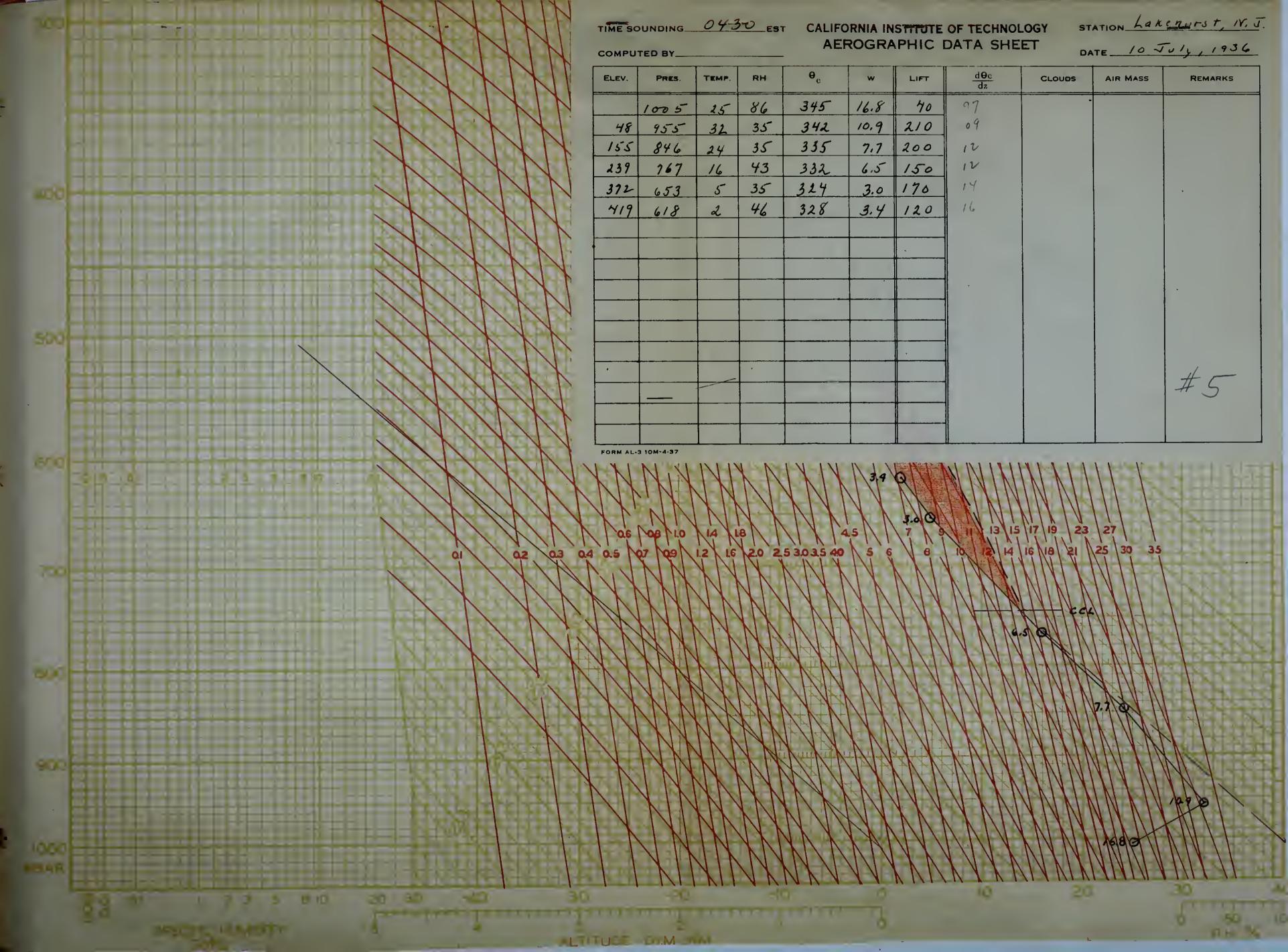
This is type 4 3, air mass thunderstorm situation.

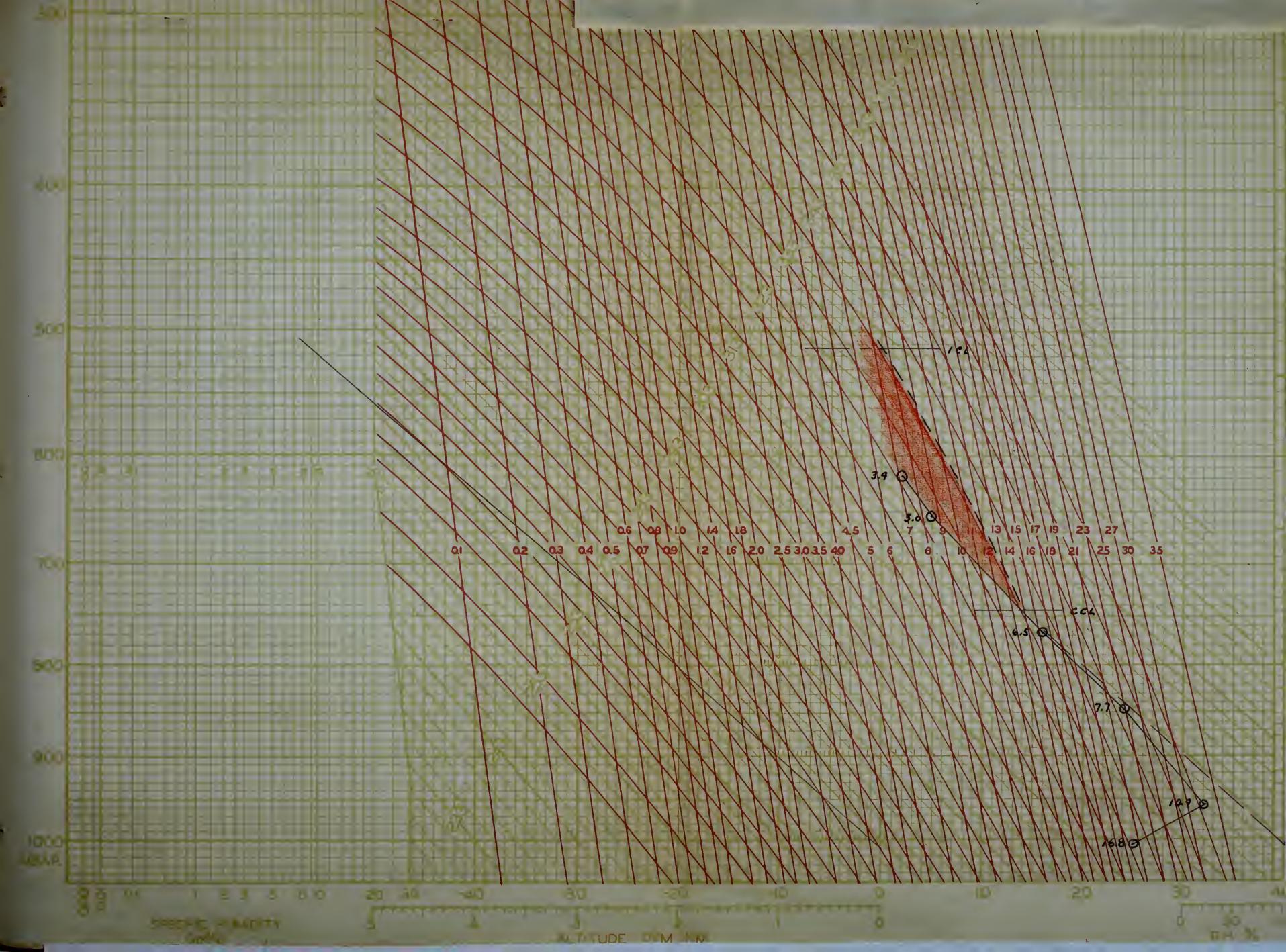
This is a situation practically identical with that at inacostia, Va. on the same day, example , 4. The only difference lies in the surface inversion being smaller and the mean specific humidity 2 grams per kilogram higher, 14 grams per kilogram in this case.

Here again the LCL is meaningless, due to the tremendous lift required, and attention is confined to the CCL.

The CCL is found to be at 744 millibars, 2650 meters. The maximum temperature required for free convection is found to be 40° C. This would seem excessive, but it was exceeded on this particular day. Then the CCL is reached by convection due to insolational heating it is found that, following the moist adiabatic up from its intersection with the CCL, the area everywhere above that point will be positive. The ICL is very high, 513 millibars, 5580 meters, and the extrapolated aerograph curve above that point appears to be closing up the positive area. However, there will be accelerations on a particle for 2930 meters, from the CCL to the ICL and for an undetermined distance beyond. A thunders torm should be predicted for the station.

high level thunderstorm of slight intensity occurred near the station at 2100. To record of type or amount of precipitation.







Anacostia, Virginia.

11 July, 1936.

This is type # 3, air mass thunderstorm situation.

This and the following case, 7, are introduced to indicate that under a given set of conditions, similar in the main points to those existing on the previous day, the same phenomena may be expected for both days.

The synoptic chart shows the forecasted that he will deal with but one air wass during the forecast period, Tog.

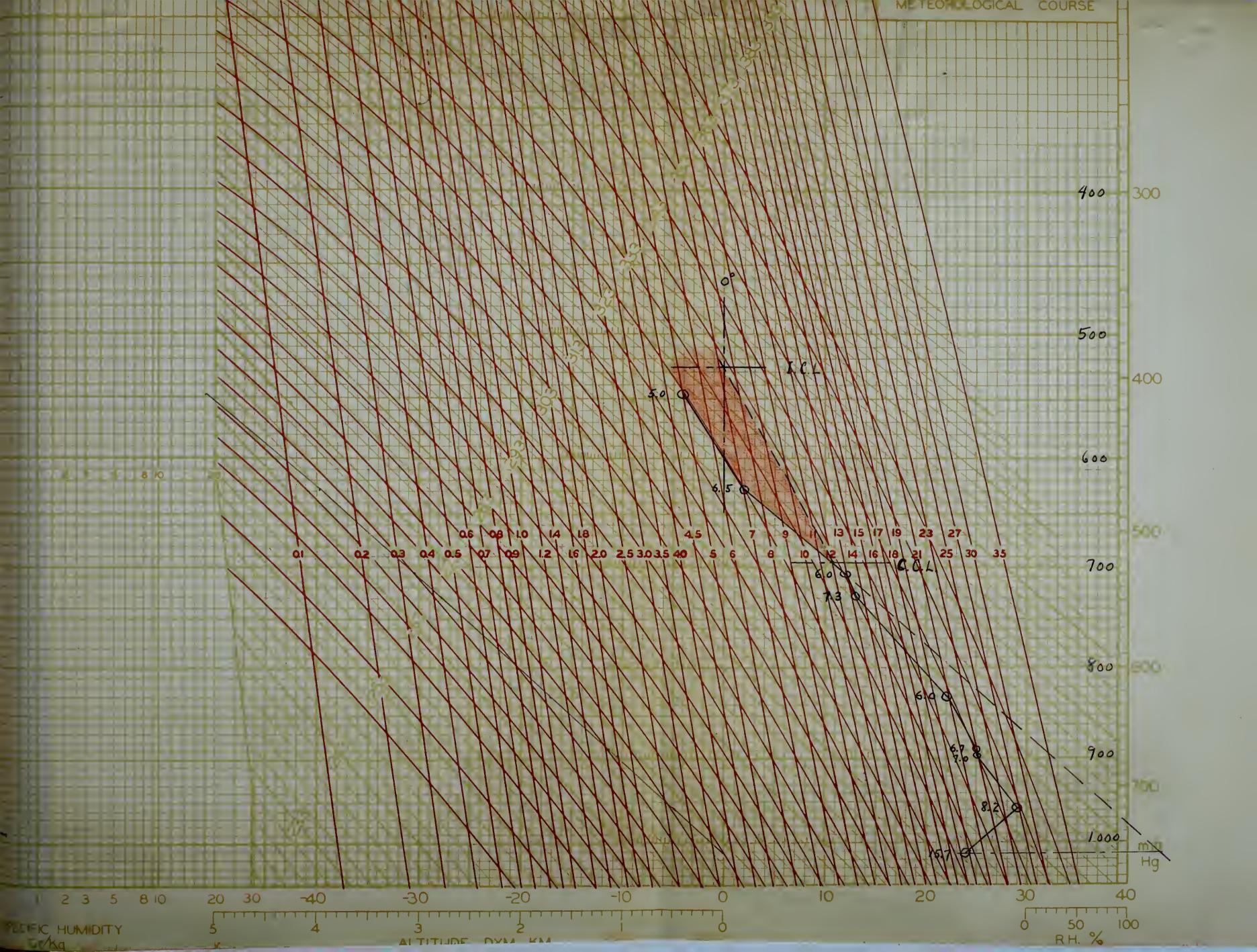
A mean value of specific humidity, 12 grams per kilogram, is chosen for the actual specific humidity of the particle to be lifted. It may be noted that the gradient of specific humidity has decreased from the previous day. The larger values aloft may be considered as due to mixing.

As before the LCL is without meaning. The CCL is found at 697 millibers, 3140 meters. The maximum temperature required for free convection is found to be 41° C. With practically the same conditions existing as on the previous day it may be assumed that this is not excessive.

When convections reach the CCL it is found that, following the moist adiabatic up from that point, the area everywhere above will be positive. The ICL is very high, 527 millibars, 5340 meters. A particle leaving the CCL will be continuously accelerated for 2200 meters to the ICL and for a distance beyond that point which cannot be estimated. A thunderstorm should be predicted for the station.

A thunderstorm occurred over the station at 1910.

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#### EXAMPLE # 7.

Lakehurst, New Jersey. 11 July, 1936.

This is type # 3, air mass thunderstorm situation.

This situation is practically identical with case #6.

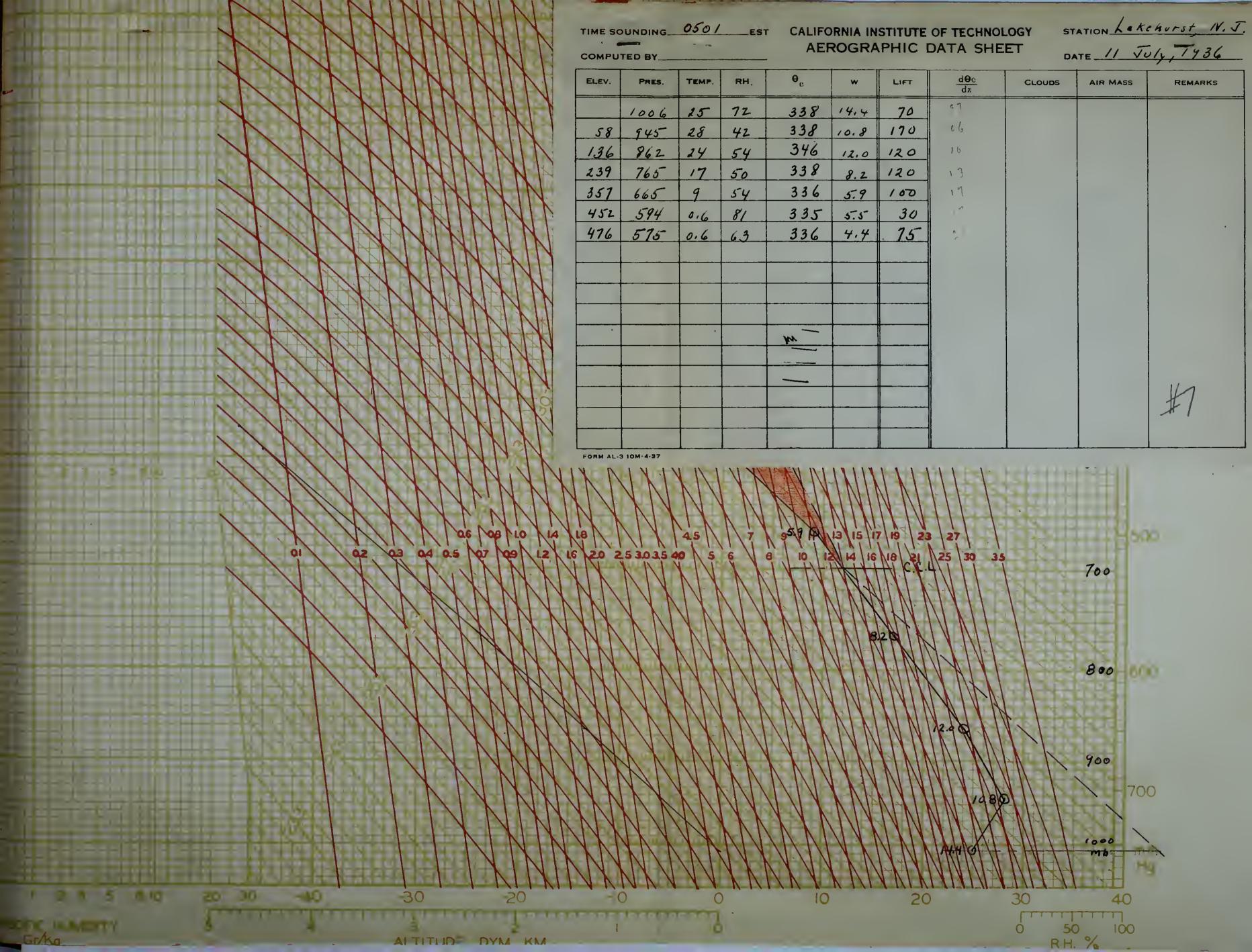
The mean value of specific humidity, 15 grams per kilogram is chosen as the actual specific humidity of the particle to be lifted.

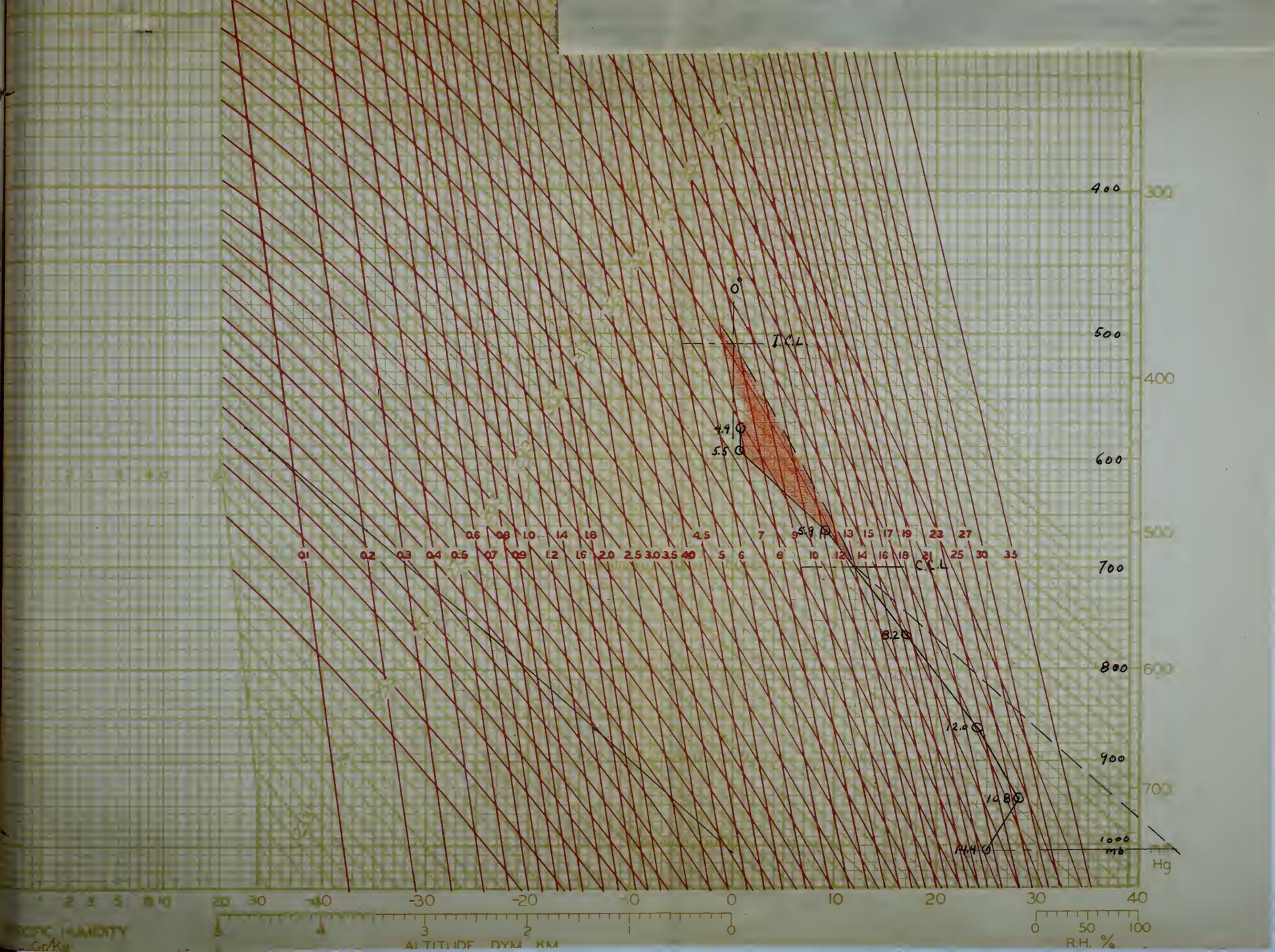
The CCL is found at 699 millibars, 3180 meters, and the maximum temperature required for free convection is 41.5 C.

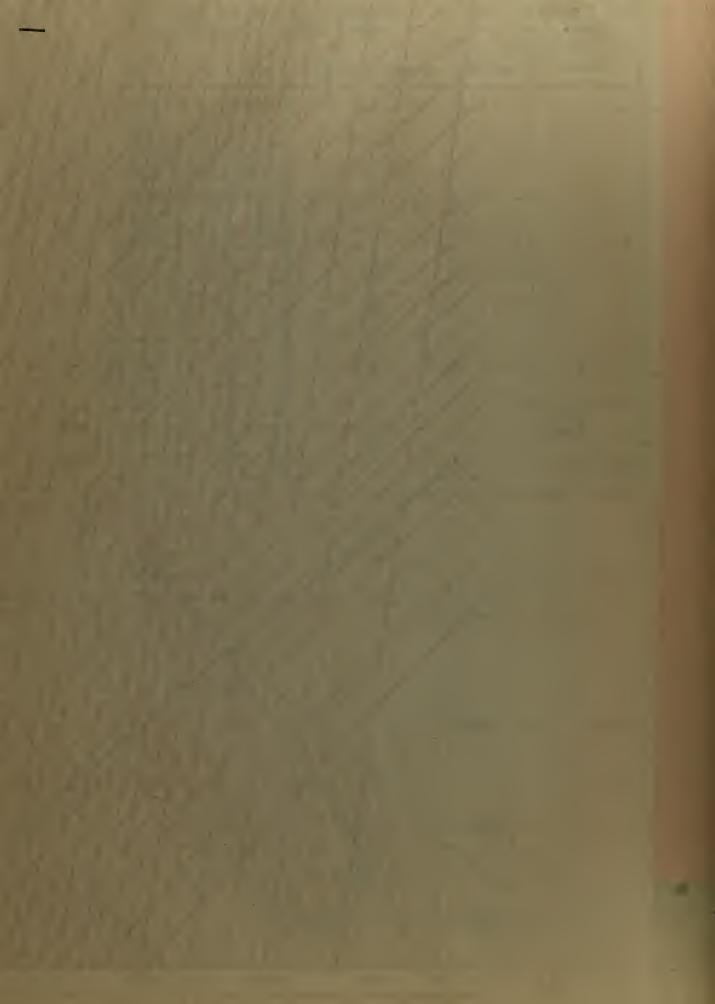
Again, considering the previous day this is not excessive.

when convections reach the CCL it is seen that, following up the moist adiabatic through this point, the area everywhere above will be positive. The ICL is very high, 508 millibars, 5700 meters. Convections which reach the CCL will be continuously accelerated from there for 2520 meters to the ICL and for a distance beyond that point which cannot be determined. A thunderstorm should be predicted for the station.

A high level thunderstorm of slight intensity occurred over the station at 2000. There was no record of type or amount of precipitation.







# EXAMPLE # 8.

San Diego, California. 4 December, 1936.

This is type # 3, air mass thunderstorm situation.

time relieve to bee now.

consideration of the synoptic chart shows the forecaster that during the forecast period he will be dealing with only one air mass, 4Pp; and that the pressure should fall for some hours, due to an approaching trough.

The actual specific humidity of the surface point, 6.3 grams per kilogram, is chosen for the situration specific sumidity of the surface point to be lifted, either orographically or convictively.

Inspection of the adiabatic chart shows the LCL at 929 millibars, 720 meters. If the moist adiabatic is followed up from this point it will show a small megative, resistant, area to 780 millibars, 2150 meters. No possibility exists at this station for the mechanical lift required to set off free convection so attention is turned to the CCL.

The CCL is found to be at 872 millibars, 1250 meters, the maximum temperature required for free convection is 17° C.

Inspection of the diurnal temperature curves for this station show that this temperature is not excessive for the date.

Followin the moist adiabatic up from its intersection with the CCL it is found that it lies to the right of the aero raph curve from 872 millibars to 620 millibars, 3080 meters, and to the left of that curve from there to the end. This means that there will be accelerations on a particle

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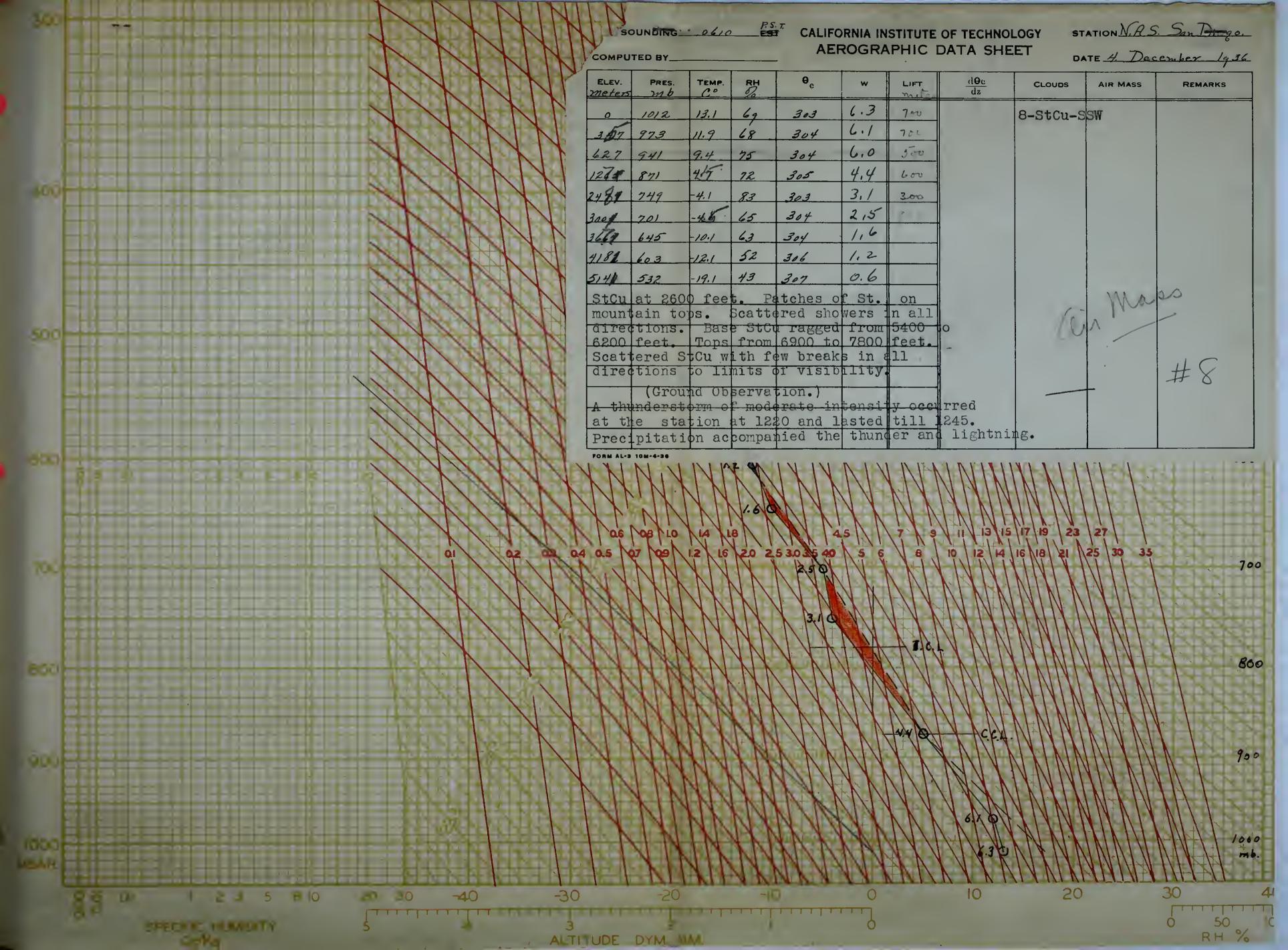
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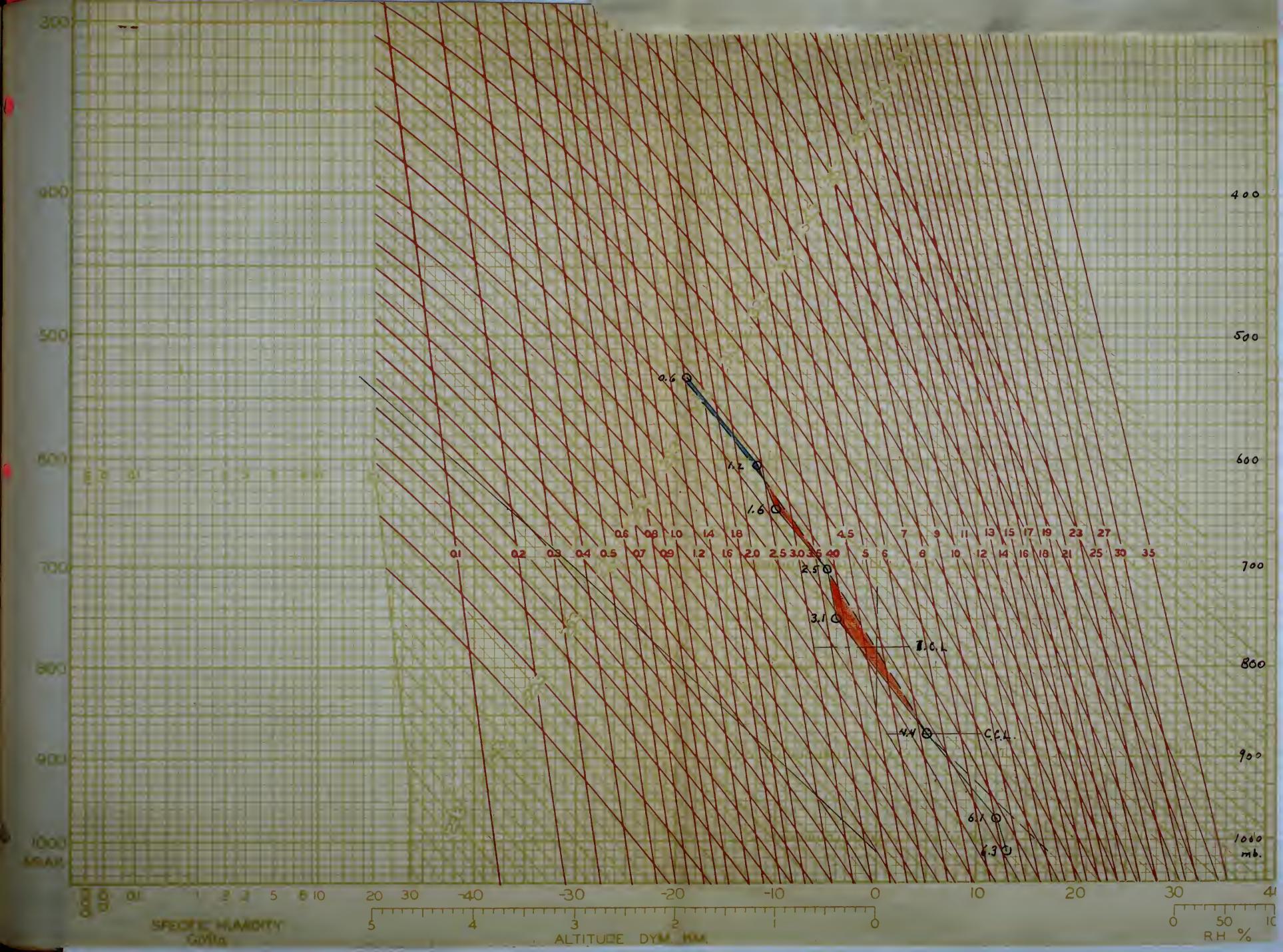
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leaving the CCL for a distance of 1730 meters to the 620 millibar level, where it will enter a resistant stratum and be decellerated until appeard velocity is completely malted at a point which cannot be determined due to the termination of the sounding. However, the ICL is at 779 millibars, 2150 meters, within the positive area. There will be accelerations on a particle leaving the CCL for 900 meters to the ICL and from there to the beginning of the resistant stratum, 330 meters further. Since it can be estimated that vertical velocities of some moment will extend for at least 2000 meters a thunderstorm should be predicted for the station. Light showers could very well be expected to accompany it, but certainly no hail.

The maximum required temperature of 17° C. was reached at 1100 at San Diegound a thunderstorm of slight intensity accompanied by light showers occurred over the station at 1240.

Although it was not needed to indicate thunderstorm possibilities, the fact that a decrease of pressure was indicated for the station would have suggested a probable increase in the instability of the ascent curve due to the development of convergence. Had the case been border line this should have been border line this should have been border line this should have







Pasadena, California. 22 Marce, 1937.

This is type # 4, air mass thunderstorm situation.

The synoptic chart shows the forecaster that he will deal with but one air mas, 2Pp1, during the forecast period.

The saturation specific humidity, 7.4 grams per kilogram, is che en as the actual specific sumidity of the surface particle to be litted, either orographically or by convection, since the station is near the seacoast and there is no inversion.

Inspection of the adiabatic chart shows that the ECL is at 970 millibars, 840 meters, as is the CCL. A moist adiabatic followed up from this point till show everywhere a positive real the elevation of Pasadena is not sufficent to provide the lift required for free convection, hills he rby in the path of the flow are high enough, though in this case lift was not necessary for insolutional heating set off the convections before the air had reached the hills. The CCL indicates that a maximum temperature of 120 C. is required to establish free convection. This temperature was reached at about the time the aerograph sounding, from San Diego, California, was made. Convections had already started when the air reached this station.

Convections will cause a rising particle to be accelerated for 1690 meters to the ICL, which is seen to be at 797 millibars, 1930 meters, and for several tousand meters

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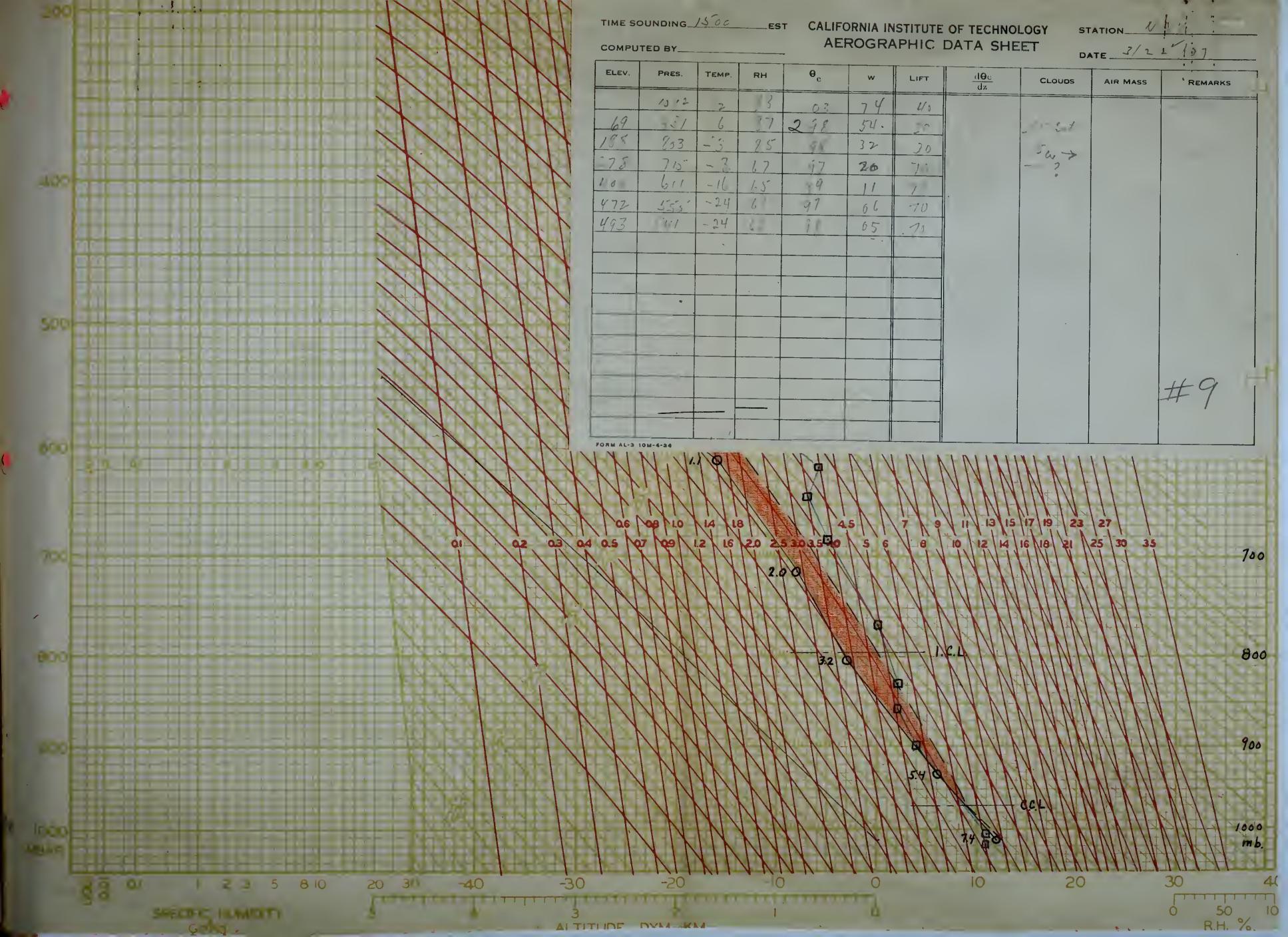
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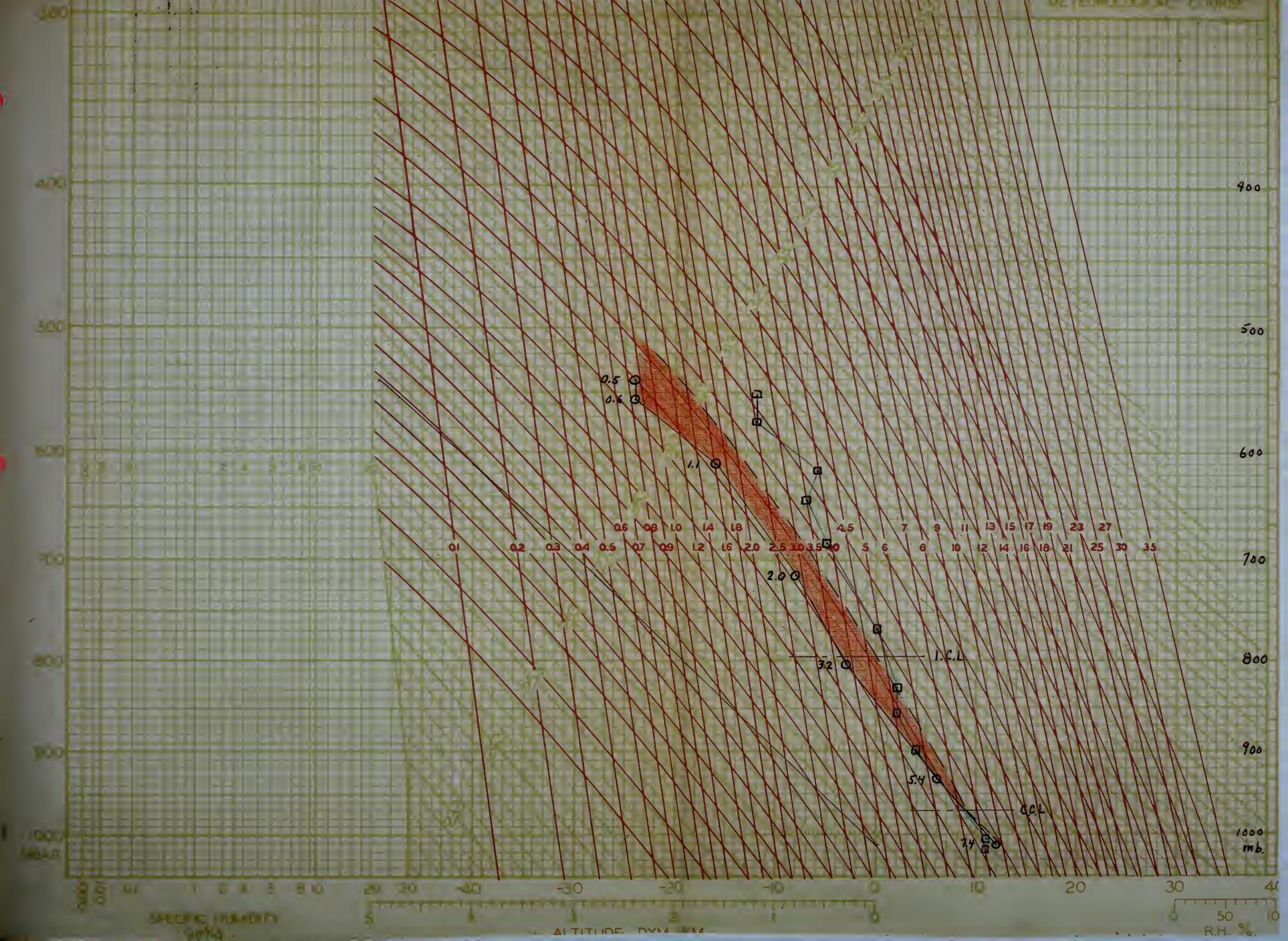
above that point. Extrapolation of the ascent curve indicates a closing of the positive area somewhat above 5000 meters.

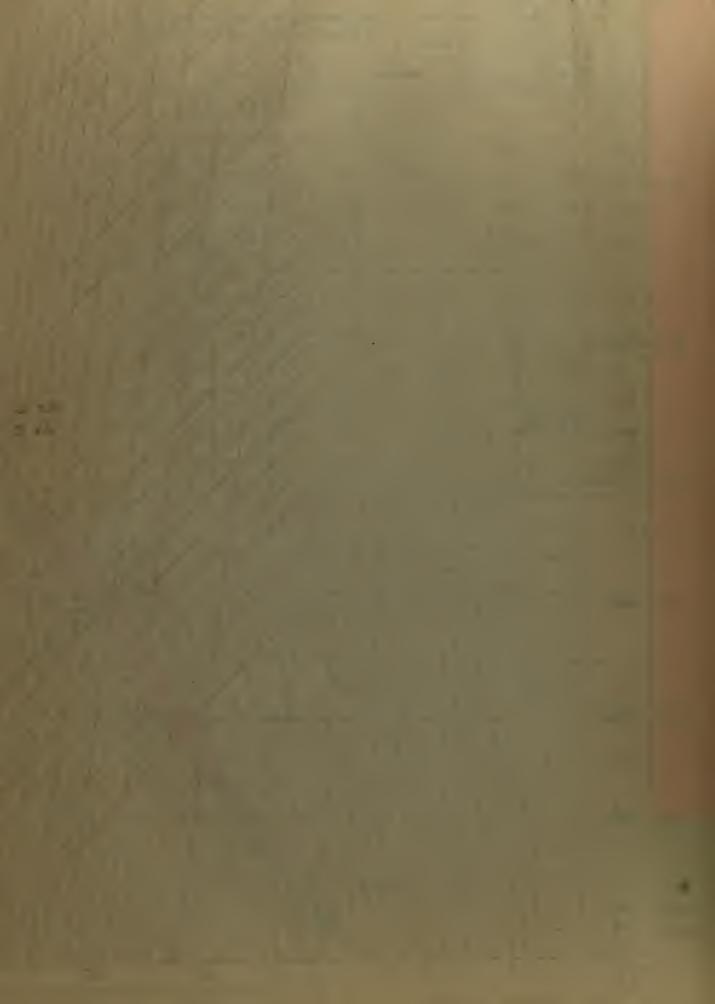
In this case, since the ICL is so low, the probability of violent electrical phenomena is remote, but the forecaster would certainly be justified in predicting hail accompanied by a light thunderstorm for the station.

A light thunderstorm accompanied by considerable hail and rain showers occurred at this station at 1245.

The ascent curve for the following day has been added to point out the stabilizing effect of subsidence, which has rendered the same air mass, violently unstable one day, stable on the following. From this curve one could predict a few strato-cumulus with bases at 950 millibars, 500 meters, and tops cut off by the stable layer at 850 millibars, 1690 meters.







Pasadena, California. 16 March, 1937.

This is type # 3, air mass thunderstorm situation.

Consideration of the synoptic chart shows the forecaster that during the forecast period he will be dealing with only one air mass, Pp.

From the adiabatic chart it is found that, within the accuracy of instruments and chart, the surface layer to 200 meters is saturated, at 10 grams per kilogram.

Convections due to insolational heating will cause the surface particle to run immediately into a resistant layer which extends to 692 millibars, 3060 meters. The diurnal temperature curves indicate that the maximum temperature to be reached during the day will not be sufficent to provide free convection.

Turning to the effects of lifting it is seen that a lift of 200 meters will so change the structure of the aerograph curve that any further lifting will result in free convection with the development of a positive area. This is shown in the curve marked in green. Since the height of Pasagena will not give the lift required for free convection no thunderstorm need be anticipated at the station.

However, the flow of air is from the west and nearby to the east of Pasadena lie hills which will provide more than enough lift to set off convective action. Since the positive area which will be developed by lift contains the ICL at

## CHANGLE # 10.

Passions, California. In march, 1937,

This is type 1 3, air mass transferators attending,

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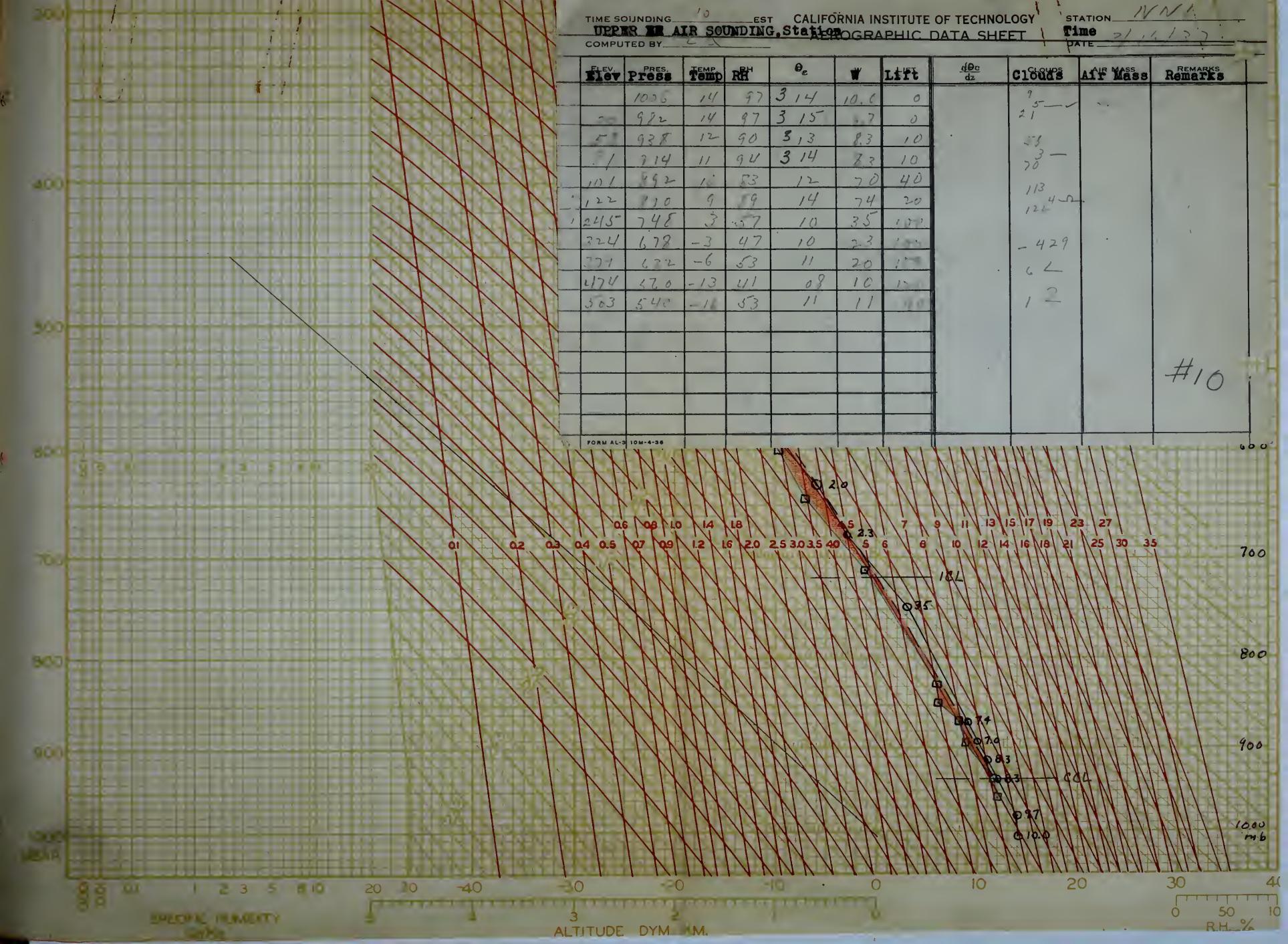
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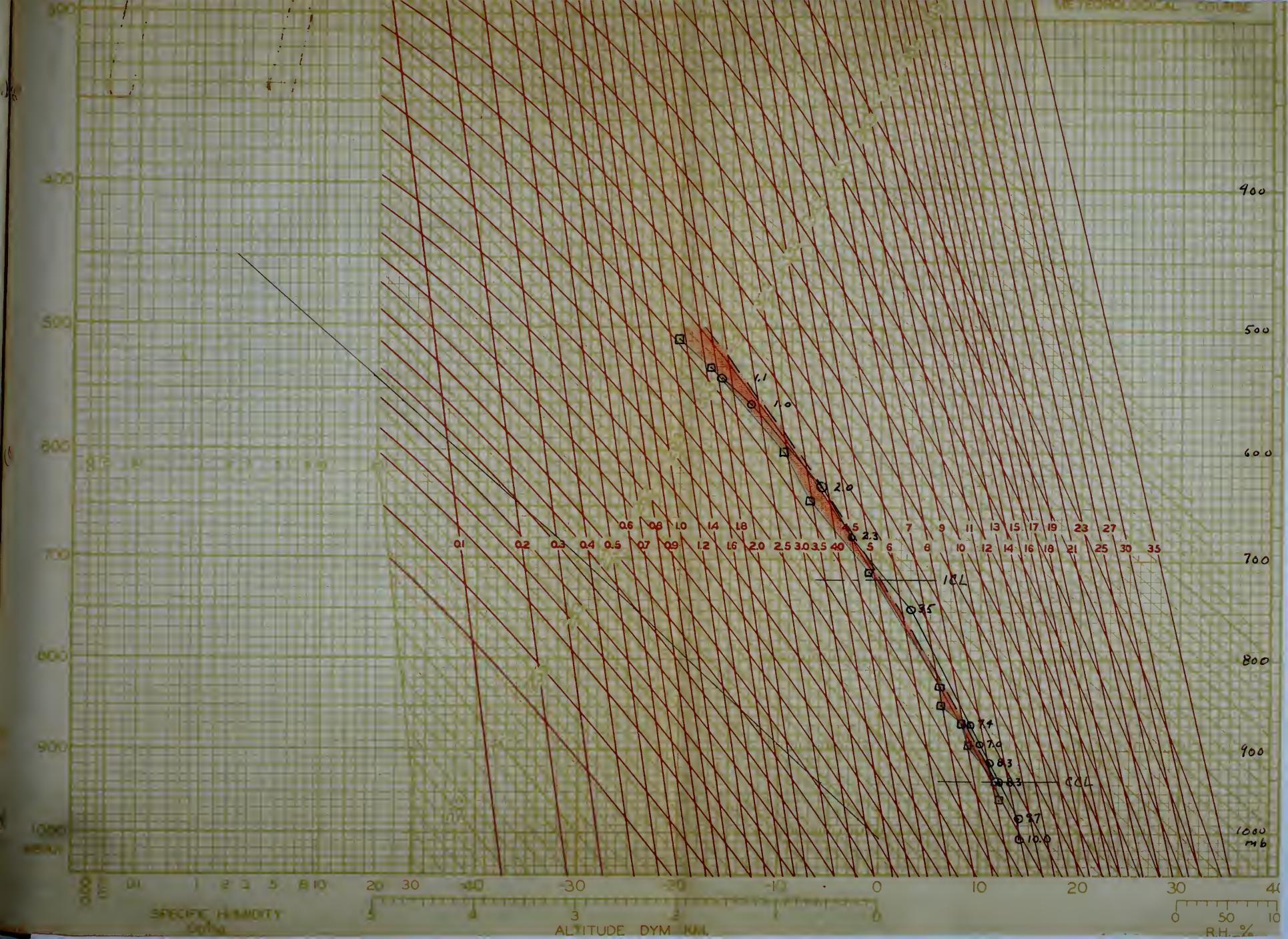
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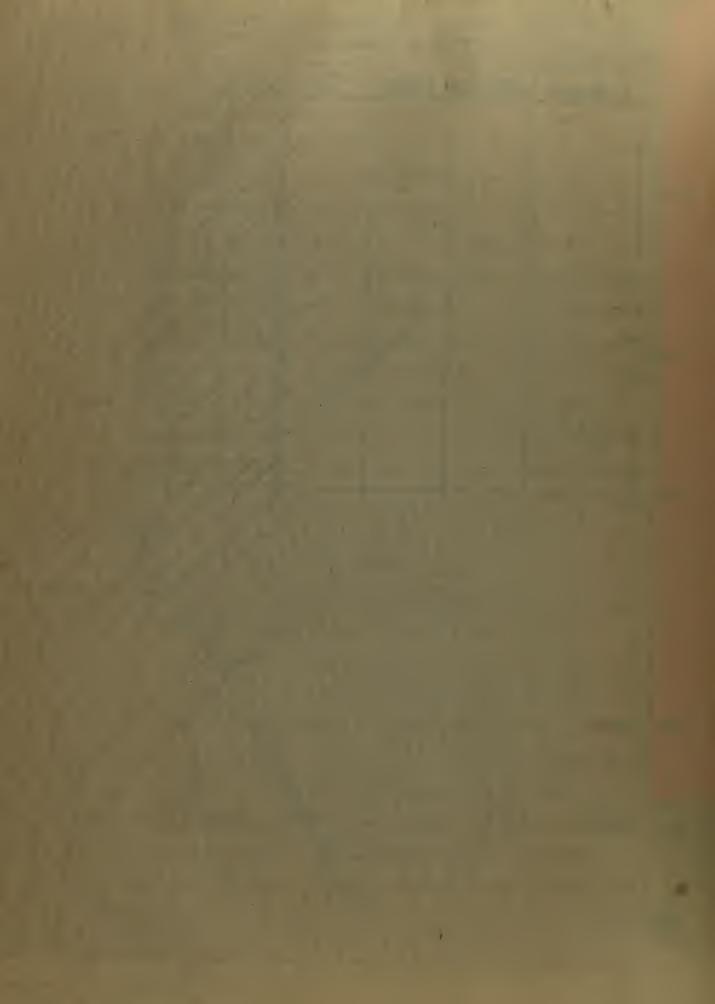
nowever, the flow of hir to from the west and nearby to the seat of framework its bills which will provide more than enough lift to set of convective action, fine the positive area which will be requisped by lift contains the ICL At

720 millibars, 2740 meters, and extends for some uncetermined distance beyond the top of the ascent curve a thunderstorm should be expected to occur in the mountains close to Pasadena.

The day was clear at Pasadena but thunderstorms accompanied by light showers occurred in the hills just to the east, starting at 1710. An increase in the intensity was reported as the air continued its flow into the higher area still further to the east.







# FRONTAL THUNDERSTORMS

Under this category are included those thunderstorms occurring in the presence of, and due to, frontal activity. This type may occur at any time of the year but is most frequently observed during the warm months. They may occur in almost every combination of air masses but due to the typical structure of conditional instability and large moisture content inherent in Tg and Ta air masses, thunderstorms will most frequently be found where this air forms the warm sector of a frontal disturbance.

Frontal thunderstorms are nearly identical in the mechanics of formation to the orographical air mass type. This may be readily seen when one considers the trajectories of air in the warm sector of a front. In the case of warm front thunderstorms the warm air is lifted by its ascent over the cold air which it is over-running, this in itself is exactly analagous to an orographic obstruction. In addition to the effects of lifting there is a certain amount of divergent flow everywhere present except near the center of low pressure. Here it should be pointed out that divergence will increase the stability of any stable layer, counteracted in some measure by the effects of lifting, but it will increase the instability of an unstable layer adding its increase of instability to that furnished by lifting after saturation.

Further, in the discussion of warm front thunderstorms, the possibility of thunderstorms occurring in the cold air

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velocities of the over-running warm air will suddenly be given an additional impulse by the intrusion of cold air. Stations in the warm air, near the surface position of the front, whose soundings had indicated them safely out of thunderstorm activity may find that, with the change in direction of motion the slope of the front will be increased, additional vertical velocities will be given the warm air and, thereby, a frequently unexpected cold front thunderstorm will be initiated. Thus thunderstorms occurring 100 to 200 miles in advance of a slow moving warm front surface position will retreat to a position some miles in advance of what is now a cold front. Cold front situation # 7, in this section, gives an example of such an occurrence.

In this section several examples of both warm and cold front thunderstorms are presented, with a brief description of what appear to be the salient features of each.

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Pensacola, Florida.

18 January, 1936.

This is type # 5, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the northwest, distant about 100 miles, on the morning of 18 January. The front is decellerating but should pass the station during the afternoon. The air masses involved are Tg at the station and the approaching mass, Pc3.

From the aerograph sounding, plotted on an adiabatic chart, it may be seen that the air mass now overlying the station is conditionally unstable from 986 millibars, 240 meters to 703 millibars, 3070 meters.

It can readily be seen that convections due to insolational heating need not be anticipated. The interest of the forecaster is then turned to the amount of lift which will be required to release the potential instability of the T<sub>5</sub> air. It is apparent from the chart that a lift of 500 meters will siturate the air from the surface to 2560 meters with the exception of a layer at 1900 meters which will be within a flow tenths of a gram of saturation. The effect of convergence, discussed earlier, should certainly overcome this small difficulty. It is possible then to conclude that a lift of anything over 500 meters will be enough to release the potential instability of the air over the station.

If the salient points of the original ascent curve are each lifted 500 meters, remembering that some will ascend the moist adiabatic, some the dry, and some will follow first the

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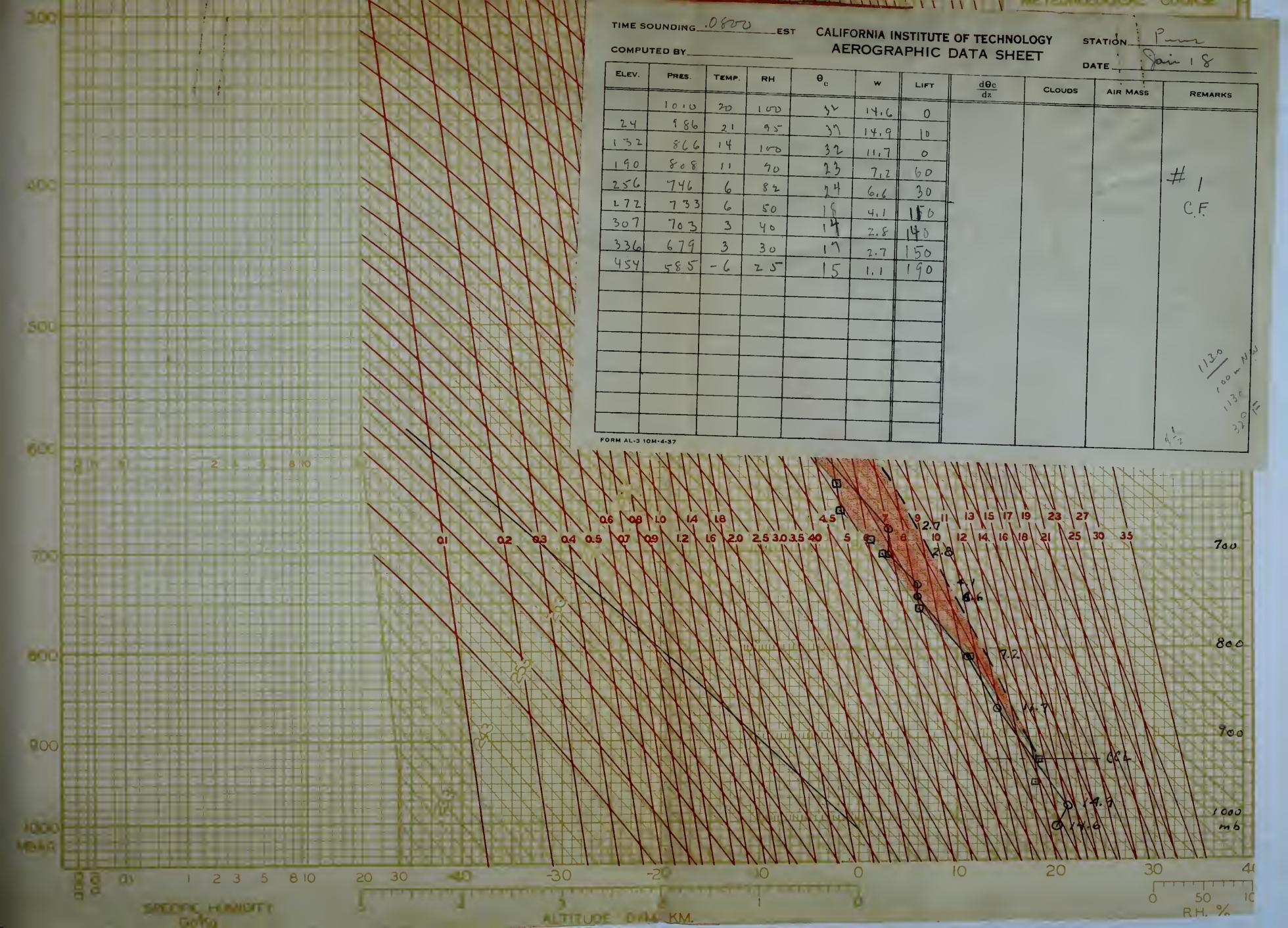
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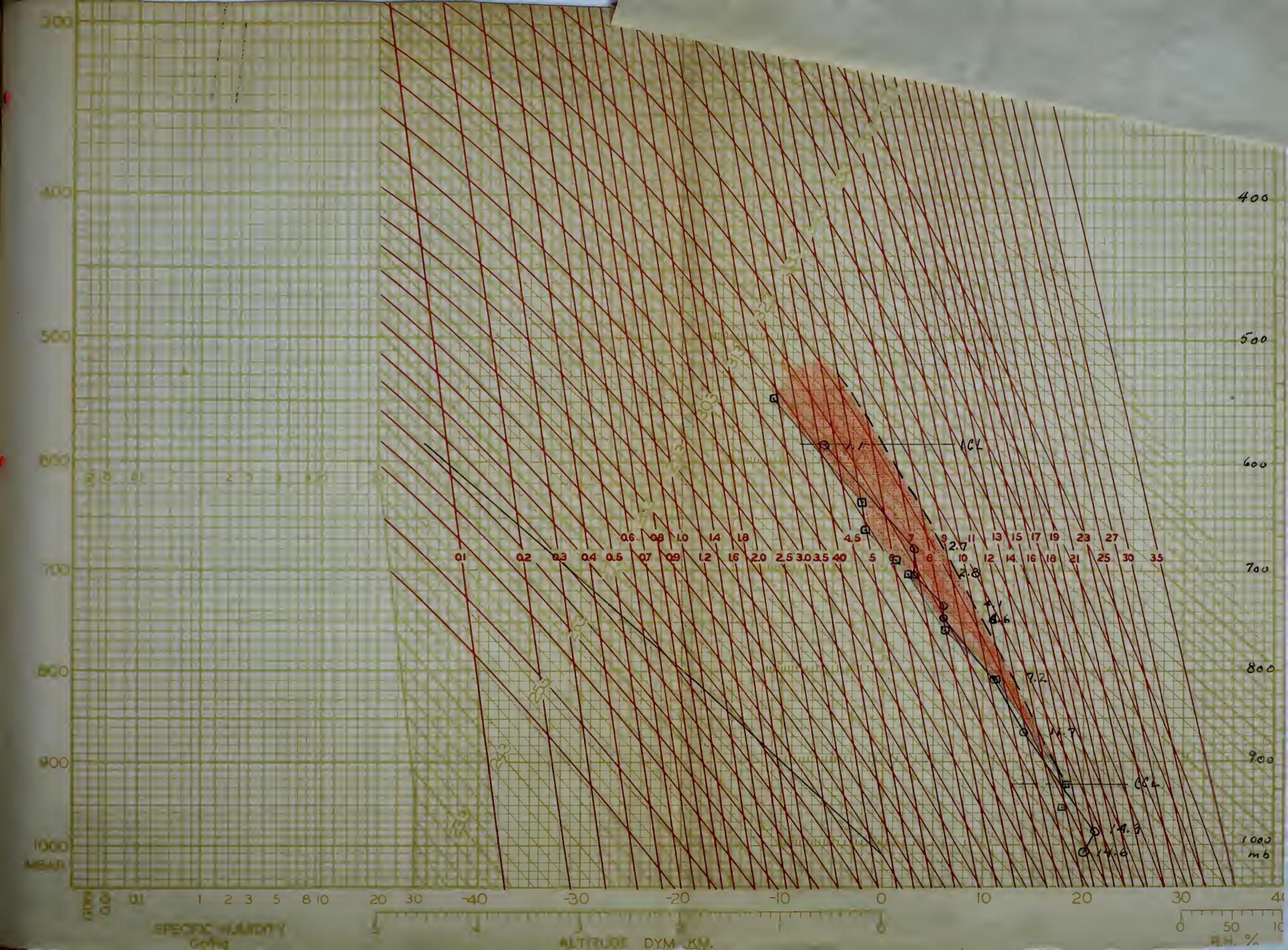
dry and then the moist adiabatic for part of the distance, curve # 2 will be obtained.

Inspection of this curve shows that further lifting will result in the rarticle which has reached 928 millibars, 740 meters, after lifting from 986 millibars, 240 meters, ascending the moist adiabatic through that point. From there upwards it will everywhere be warmer than its surroundings and will be continuously accelerated. There will be a positive area from 928 millibars, 740 meters, to the top of the ascent curve. The ICL is contained within this area at 590 millibars, 4470 meters.

The forecaster may conclude that with a lift of anything over 500 meters, certainly to be expected from the approaching fro t, there will be free convection extending from 740 meters, with continuous accelerations from there to the ICL at 4470 meters and increasing beyond that point for a distance which cannot be estimated. He should predict a thunderstorm, accompanied by moderate rain and hail, for the station during the first forecast period.

A thunderstorm occurred over the station at 1135, the front passed the station at 1500 with a rapid drop in temperature of 18° C. Unfortunately there is no report of the type of precipitation.







Pensacola, Florida. 8 June, 1936.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for the morning of 8 June shows a culsi-stationary front to the northeast of the station with a wed e of high pressure to the north. Such motion as the frent has experienced has been generally toward the southwest, ast of the station, and north to the west. The air masses involved are Tg, oPp and Fc4.

From the aerograph curve, plotted on the adiabatic chart, it may be seen that the air mass overlying the station is conditionally unstable, in effect, throughout. There are small stable strata, but in the main the mass is conditionally unstable.

Examination of the chart shows the CCL, using 17 grans per kilogram as the actual specific humidity of the surface particle, to be at 884 millibars, 1220 meters. A maximum temperature of 31.5 C. is required for convection to reach that level. The diurnal temperature curves indicate that this will probably not be reached during the day so attention is given to the LCL. If certainty existed that there would be no frontal activity near the station the fact that the LCL is found to be at 958 millibars, 540 meters, would indicate that no further thought of thunderstorms need be in the forecasters mind. However, in view of the front near the station and the possibility of development of movement thereon it would be well to find what lifting would do to the air mass structure.

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Pensagola, Florida.

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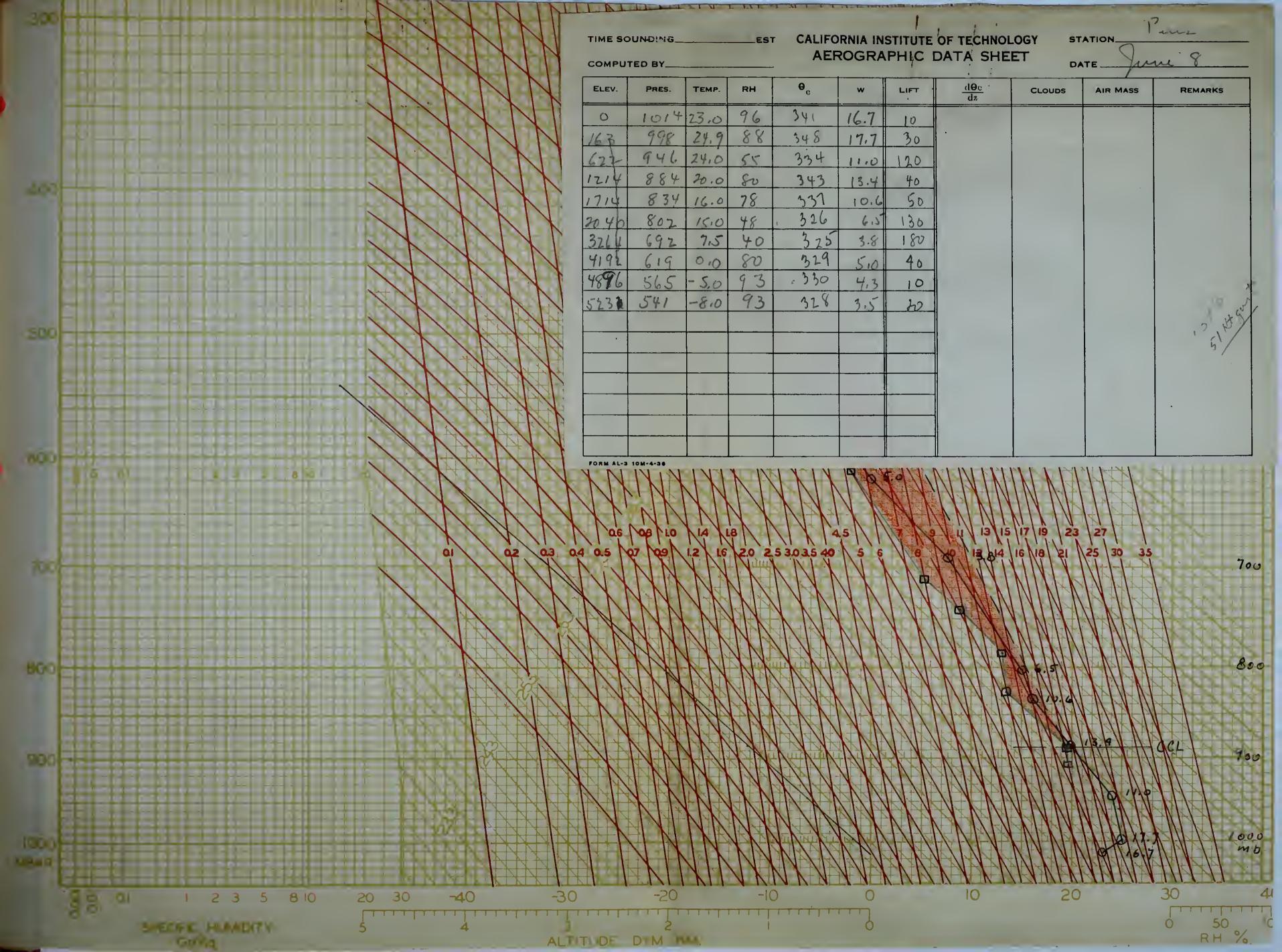
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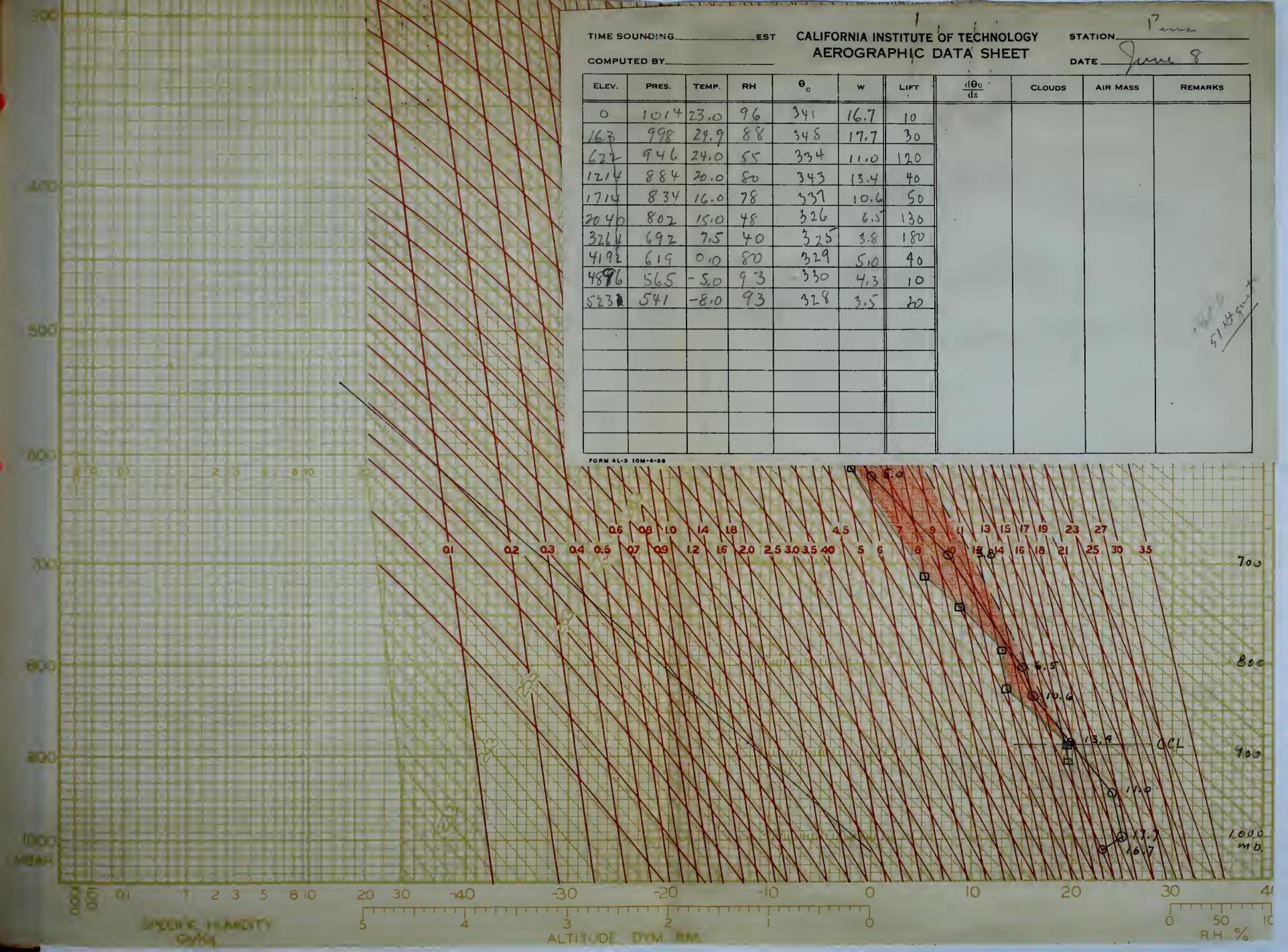
If the salient points of the original ascent curve are lifted 1000 meters, a reasonable lift considerin, frontal activity, curve 4 2 will be obtained.

Inspection of this curve shows that further lifting will result in the particle which has reached 890 millibers, 1180 meters, after lifting from 998 millibars, 163 meters, ascending the moist adiabatic through that oint. From there upward it will be warmer than its surrou dings and will be continuously accelerated. So with further lifting there will be a positive are extending from 890 millibers, 1180 meters to the top of the ascent curve. The ICL is contained within this area at 542 millibars, 5220 meters.

The forecaster may conclude that in the case of regeneration of frontal activity and approach to his station, he will have the probability of free convections extending from 1180 meters, with continuous accelerations, to the ICL at 220 meters and for a distance beyond that point which cannot be estimated. He should carefully watch his teletype reports, if available, and be prepared to give a supplementary forecast of moderate thunderstorm, accompanied by rain and hail, for the station if the front approaches.

In this case regeneration of the front occurred, motion toward the southwest was rapid, and a moderate thur erstorm passed over the station at 1610. Gusts of 51 knots were recorded during the thunderstorm but unfortunately the type of precipitation was not reported.







Lakehurst, New Jersey. 13 May, 1936.

This is type # 3, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the west, distant about 180 miles on the morning of 13 May. The front is moving steadily eastward at about 20 miles per hour and should pass the station in the late afternoon. The air masses involved are Tg2 at the station and the approaching mass, oPo.

mass now overlying the station is conditionally unstable for the greater part. Inspection shows that a maximum temperature of 35°C. is required for convections to reach the CCL, a temperature which far exceeds any to be expected at the station. The interest of the forecaster is then turned to the amount of lift required to release the potential instability of the air. In view of the approaching front a lift of 1000 meters is applied to each of the salient points of the original ascent curve. Curve # 2 is obtained by this operation.

Inspection of this curve shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 725 millibars, 2820 meters. It is also to be noted that above 772 millibars, 2340 meters, the new curve lies to the left of the moist adiabatic through that point. With any further lifting a positive area will be developed from 772 millibars, 2340 meters, to the top of the curve. The ICL is contained within this

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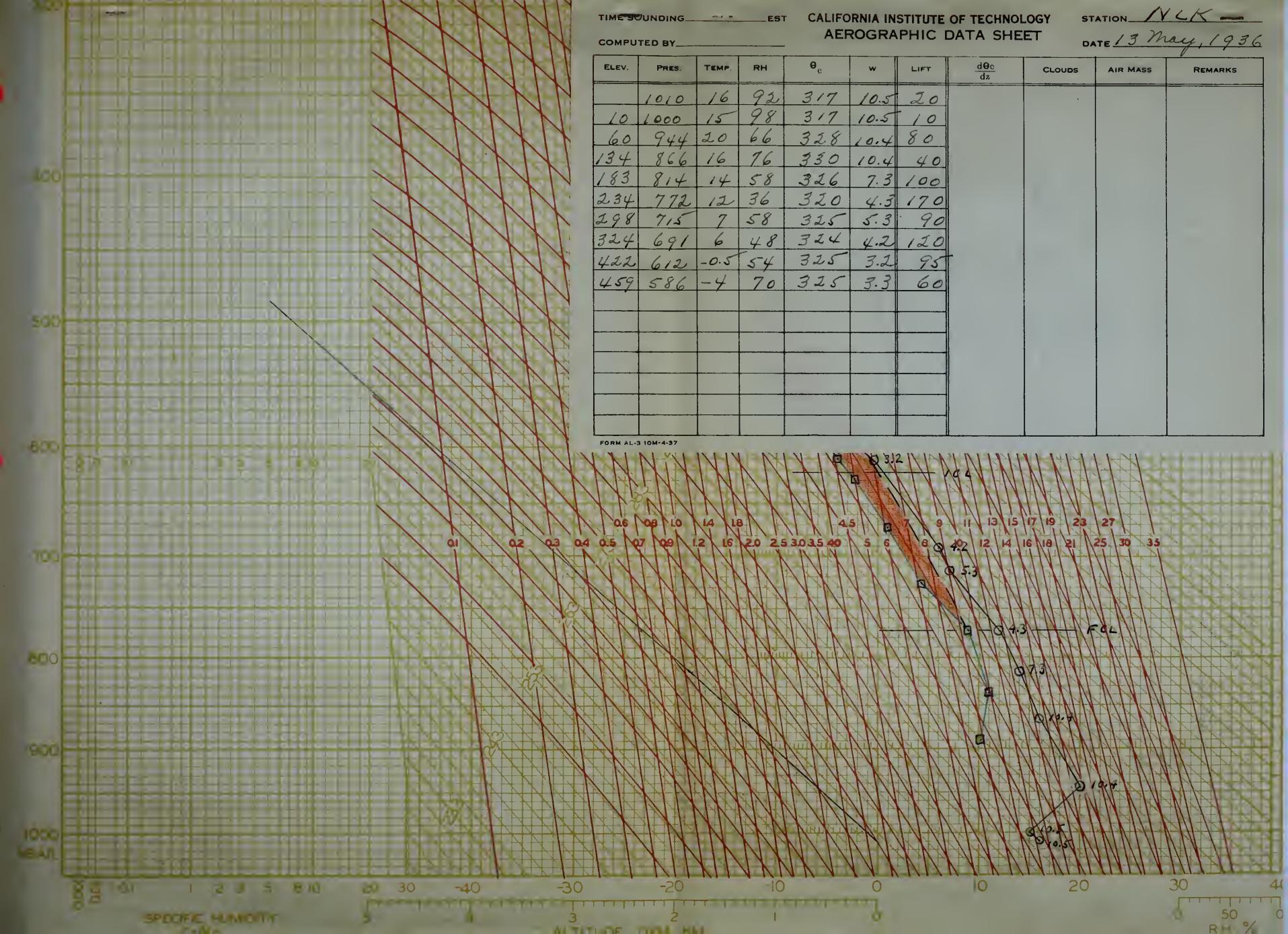
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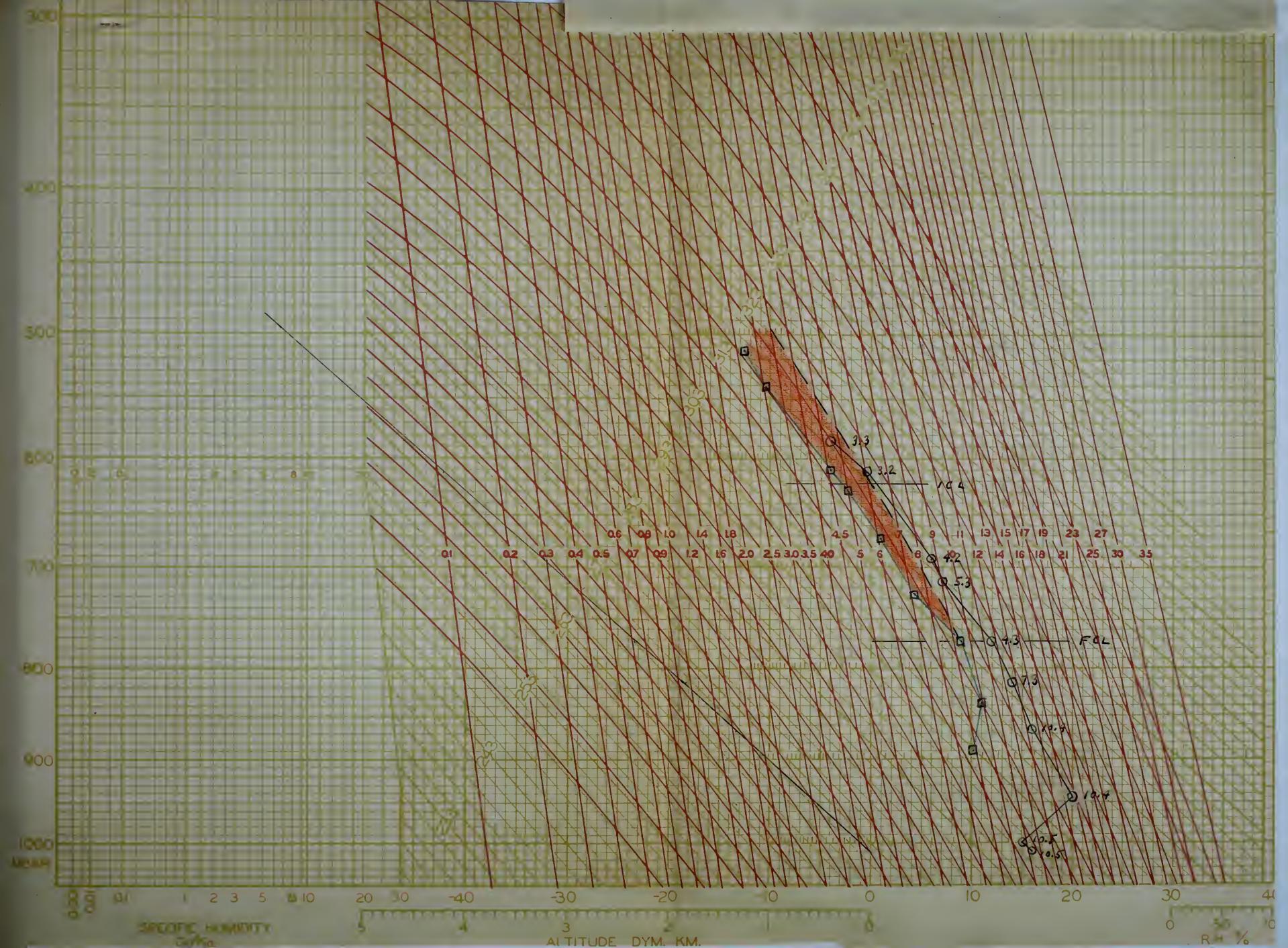
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area at 622 millibars, 4100 meters.

The forecaster may be assured that with a lift of anything over 1000 meters, certainly to be obtained from the approaching front, there will be free convection extending from 772 millibars, 2340 meters, with continuous accelerations, to the ICL at 4100 meters and above that point for a distance which cannot be estimated. A thunderstorm, accompanied by rain, should be predicted for the station for the first forecast period.

A thunderstorm occurred over the station at 1500, unfortunately the type of precipitation was not reported. The cold front passed the station at 1730.







Anacostia, Virginia. 13 May, 1936

to the top of the sa

This is type # 3, cold front thunderstorm situation. The synoptic chart shows a cold front approaching the station from the west, distant about 140 miles on the morning map. The front is moving east steadily at about 20 miles per hour and should pass the station during the afternoon. The air masses involved are Tg2 and oPo.

From the aerograph curve, plotted on the adiabatic chart it may be seen that the air now overlying the station is conditionally unstable throughout the greater part. Inspection shows a maximum temperature of 33.2 C. required for free convection induced by surface heating, a temperature which exceeds the normal for the date at the station.

The amount of lift which will be required to release the potential instability of the air is now investigated. In view of the approaching front a lift of 1000 meters is applied to each of the salient points of the ascent curve. Curve # 2 is obtained from this operation.

Inspection of this curve shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 625 millibars, 4120 meters. It is also to be noted that above 820 millibars, 1890 meters, the new curve is everywhere to the left of the moist adiabatic through that point. With any further lifting a positive area will be developed from 820 millibars, 1890 meters,

## SCAMPLE W 4.

Ansecatia, Virginia.

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The synoptic chart shows a cold front approximation the exact of exact approximating the exact or from the meet, distant about 197 miles on the more ing map. The front is moving each abouting at about 20 miles per hour and should pass the station during the mitermoon.

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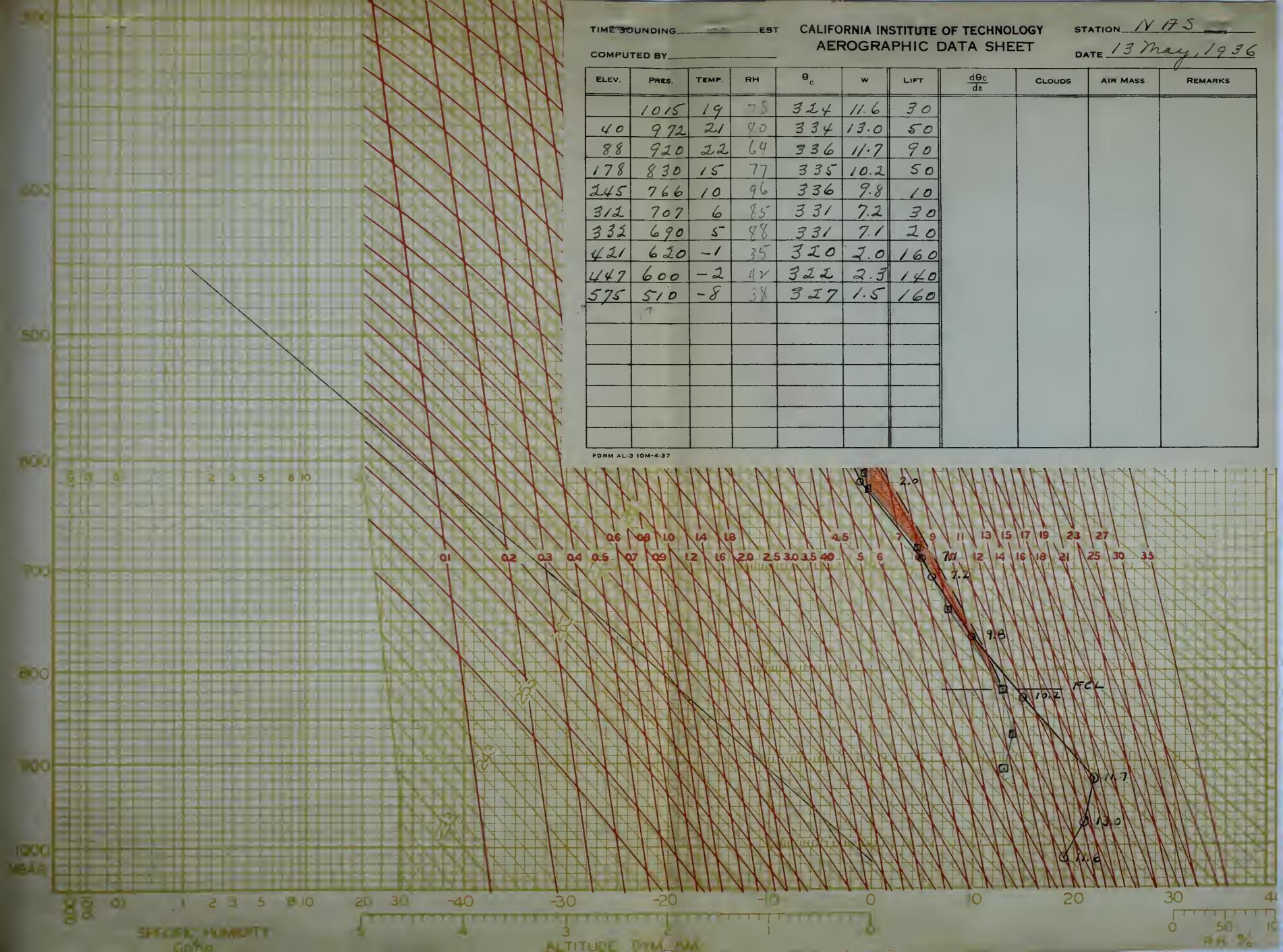
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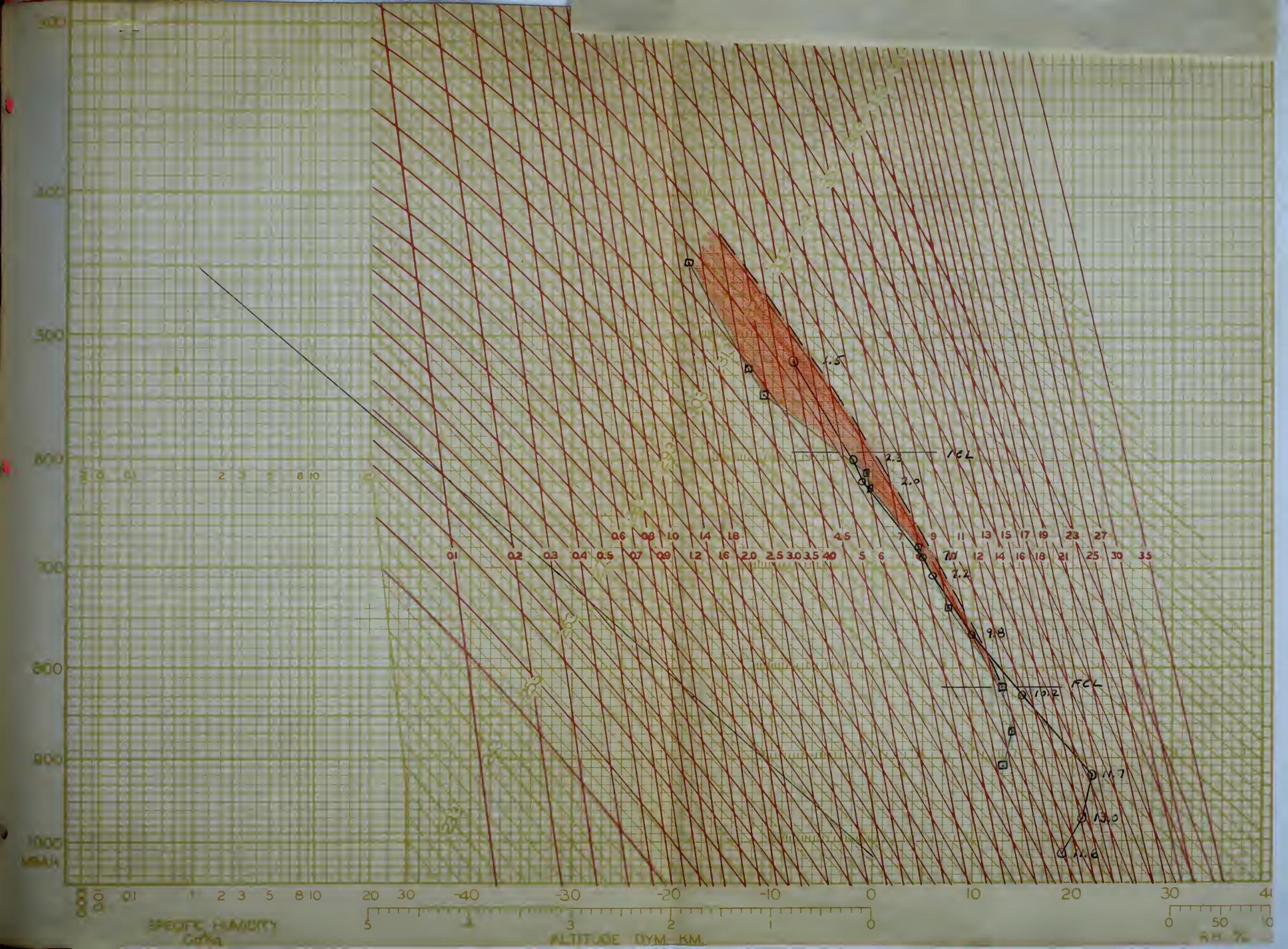
Ourse of is obtained from this operation.

Inspection of this ourse shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 680 milithars, 4100 Forers. It is also to be noted that above 820 militars, 1800 setters, the new serve is opergobers to the left of the moist witabelis through that roint. With any further lifting a postive area will be developed from 500 militars, 1600 maters, to the top of the curve. The ICL is contained within this area at 600 millibars, 4480 meters.

The forecaster may be assured that with a lift of anything over 1000 meters, certainly to be obtained from the
approaching cold front, he will have free convections extending from 820 millibars, 1890 meters, with continuous
accelerations to the ICL, a distance of 2590 meters, and
for a distance beyond that point which cannot be estimated.
He should predict a thunderstorm, accompanied by moderate
rain, for the station during the first forecast period.

A thunderstorm occurred over the station at 1430. Unfortunately the type and amount of precipitation was not reported. The cold front passed the station at about 1530.







Northeast Arkansas. 23 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for 22 April shows a rather complicated cold front running St.-Mt through the panhandle of Texas and moving to the southeast at approximately 22 miles per hour. A flow of Tg is being brought north, induced by the low pressure centered in Iowa. The air masses involved are Tg and 3Pp5 in the warm sector, 1Pp3 and Pc3 behing the cold front.

This example passes from station forecasting to the wider range of district, for the investigation of the weather phenomena associated with such a rapidly moving and complicated frontal system must be more general.

In this case it is seen from the Ehreveport sounding for 22 April that To air has reached there, at least in the surface levels. Judying from the cloud drift the upper winds are enerally south, veering to southwest. The velocities can only be estimated, but from such pilot balloon runs as are available it seems that they approach 35 miles per hour.

Plotting the Shreveport sounding on an adiabatic chart it is seen that, with the present structure, the air over that station now will not be susceptible to convections due to surface heating. Going to the lifting process, remembering that the swiftly moving front to the northwest will provine a ready agency for lifting, the salient points are each lifted 1000 meters. From this operation curve # 2 is obtained,

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The symoptic chart for 62 April above a fitter compilerated cold from tunning ST-WE through the pathemile of Texas and neving to the southeast at approximately 22 miles per hour. A firm of Mr is being brought north, induced to the low pressure contered in lows. The air manner through the old from the sector, jepg and jeg health the cold from.

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with saturation extending up to 729 millibars, 2800 meters, Tith further lifting that air now at 839 millibars, 1610 meters, will ascend the moist adiabatic through that point. It will provide a positive area from there to 715 millibars, 3000 meters, where it will run into a resistant area, the remains of the strong inversion from the original curve. This resistant area extends to 552 millibars, 5380 meters, and it is believed that it will be strong enough to block convections at that point. It can be seen that either further lifting must be anticipated or that the probable effects of convergence be applied to see what will r sult.

Assuming 20% convergence of mass due to the rapidly moving front, and remembering that convergence is applied to the pressure difference between each salient point and the surface point, presuming mass roughly proportional to the pressure, curve 3 is obtained from curve 2. It is seen that this last manuever has reduced the inversion of the original curve to a point where its maximum point lies just on the moist adiabatic which passes through 830 millibars, 1700 meters. The resistant area has been completely destroyed and there could be free convection from 1700 meters to the top of the curve, lith accelerations being continuous but a minimum at 600 millibars, 4400 meters, increasing thereafter.

However, realizing that there is no quantitative means of measuring convergence and that its use is merely a guess as to the amount to expect, the original ascent curve is again operated on, this time using 1500 meters lift. From this

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operation curve # 4 is obtained. From this curve it is seen that any further lifting will result in the formation of a positive area extending from 702 milliburs, 2100 meters, to 618 milliburs, 4150 meters, there a slight resist nt area is encountered, 28 milliburs, 400 meters, thick. This would not prove an obstacle and convection would pass through that layer above which lies mother positive area increasing in size to the top of the curve. The ICL lies at 680 milliburs, 4140 meters. Attention is invited to the similarity of curves # 3 and # 4, indicating that in this case a convergence of 20% is practically equivalent to a lift of 500 meters.

The air, now over Shreveport, if lifted 1500 meters, or 1000 meters with an assumed convergence of 20, will be in a state where any further lifting will result in the religation of the potential instability contained therein. Thunderstorms should occur, accompanied by hail and rain.

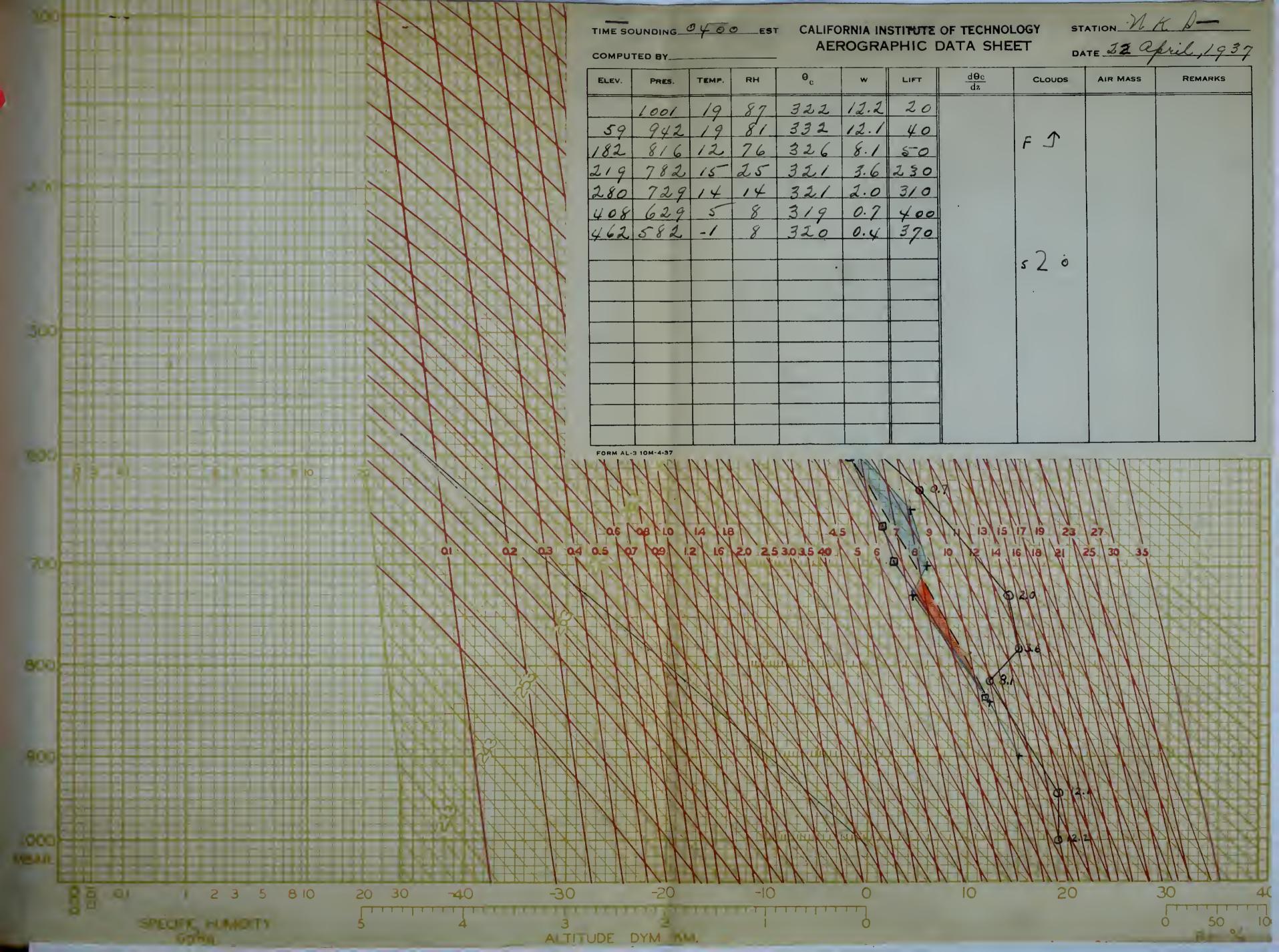
The next question to consider is, where may it be expected that this lift will be realized? Considering the flow of To to be about 35 miles per hour from the southwest, veering to west with northerly distance gained, and the computed or extrapolated movement of the front to be about 22 miles per hour in a southeasterly direction it appears that the southern part of Illinois and a line extending from there southerly through vestern Louisiana should have cold front thunderstorms of considerable intensity starting early on 13 april.

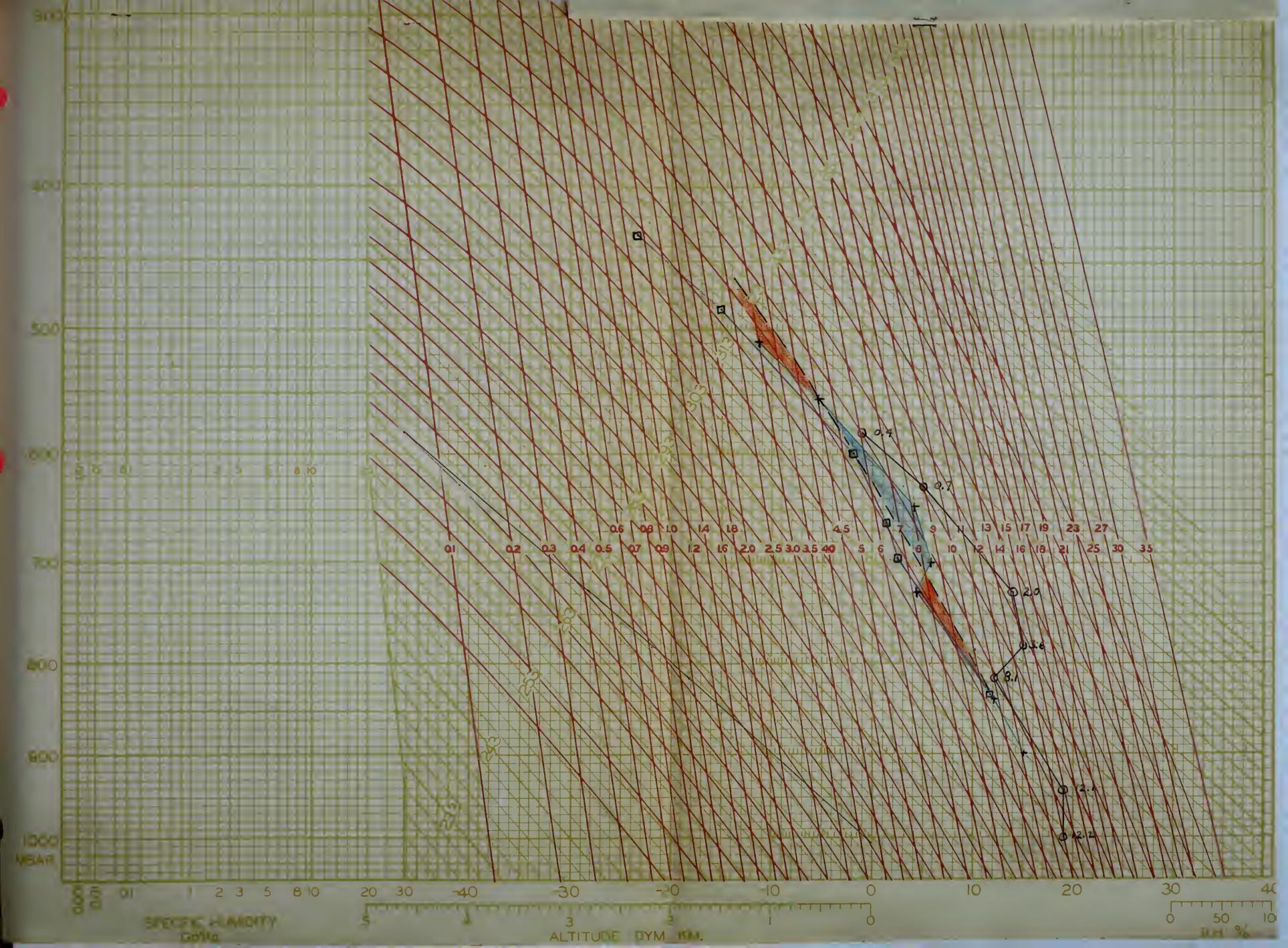
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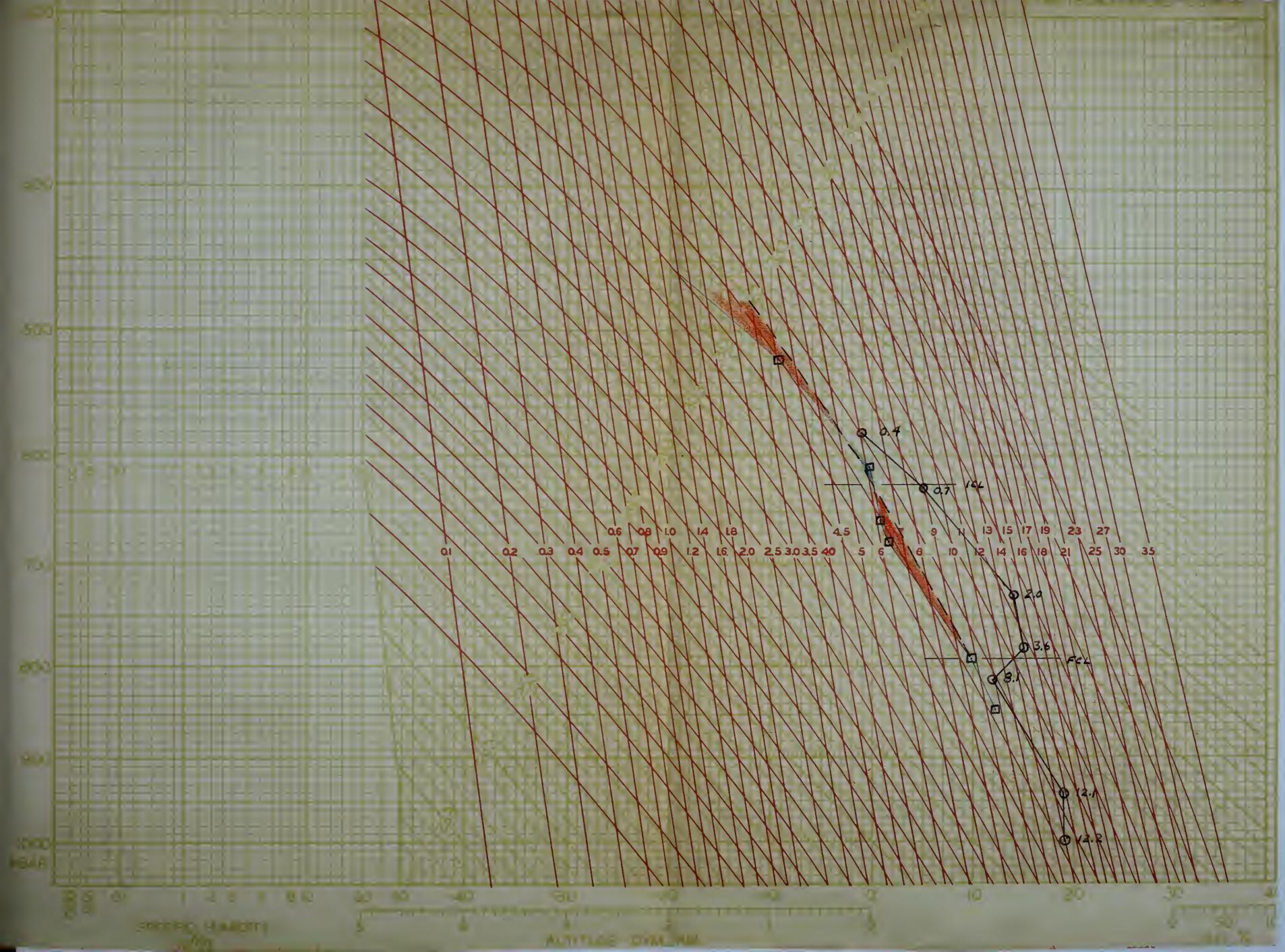
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Thunderstorms of considerable intensity, accompanied by destructive hail in northeast Arkansas, and extended over a long line running from there to the south-southwest, started during the night of 22-23 April and continued long the cold front during the 23rd. Tornado-like winds occurred long the front during the night.











Dallas, Texas. 29 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart shows a cold front 130 miles to the west of Dallas on the morning of 28 April. It is moving to the east and decellerating. The air masses involved are ofco approaching Tg in the warm sector with 4Ppp and RPc, the cold masses.

In view of the synoptic situation the air mass structure which would interest the Dallas forecaster is not that overlyin his station at the time of the morning map but rather that which will be over Dallas when the cold front is in close enough proximity to his station to be an active lifting arent. Judging from the upper air soundings at the pilot balloon run the air mass which is now over San Antonio, and whose aerograph sounding is available, is the air most similar to that which should be over Dallas at a time when frontil activity may be expected. In the absence of any better data the forecaster must use this sounding to estimate the structure of the air.

The San Antonio aerograph sounding was taken at 1000 C.S. 28 April. Plott d on the adiabatic chart it is seen that this air with its strong inversion will not be susceptible to convections due to surface heating. Considering the possibility of lift, since a front is approaching which will serve as a ready lifting agent, it is seen that a lift of ap roximately 2000 meters will be required to remove the inversion. The

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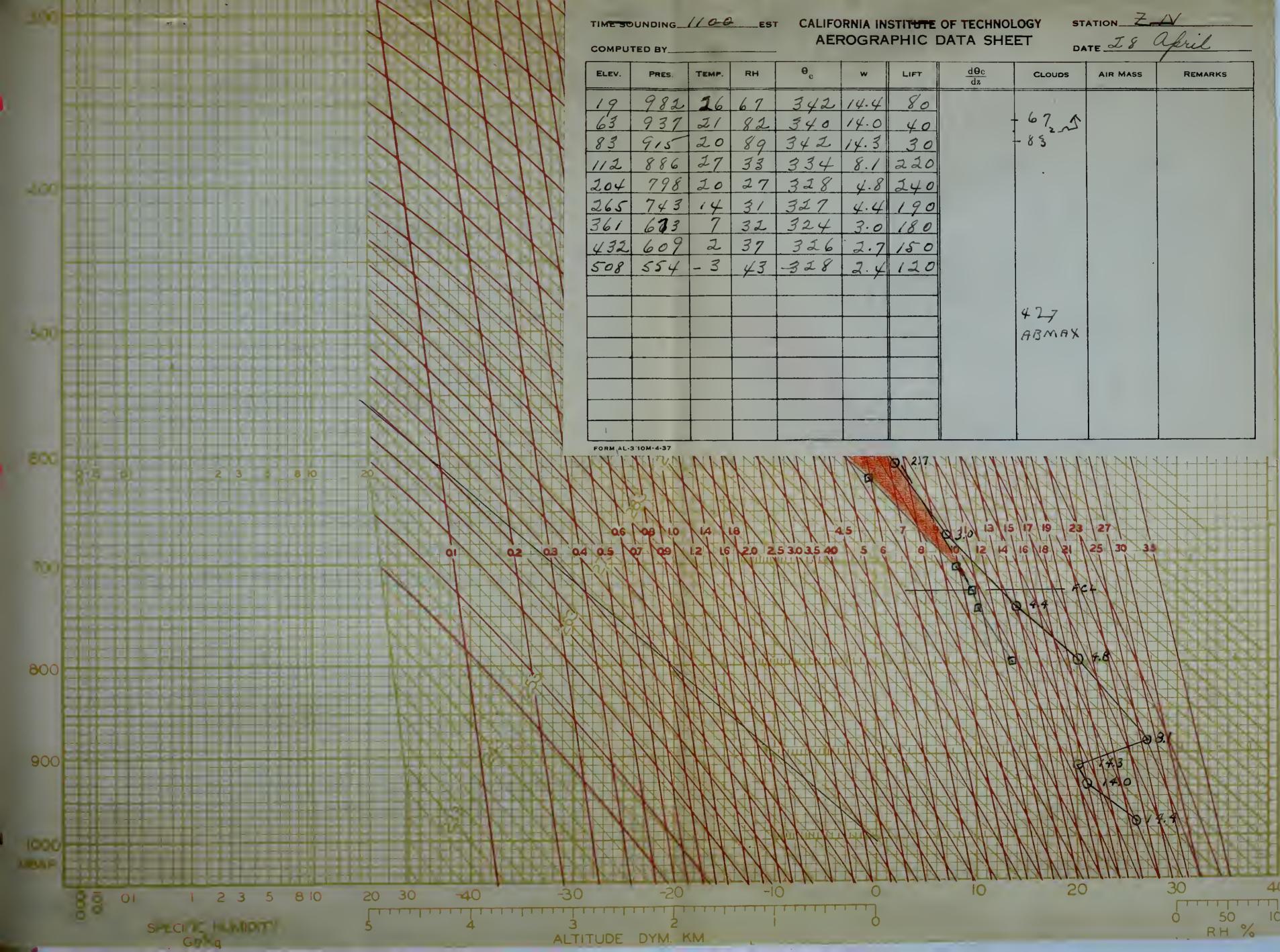
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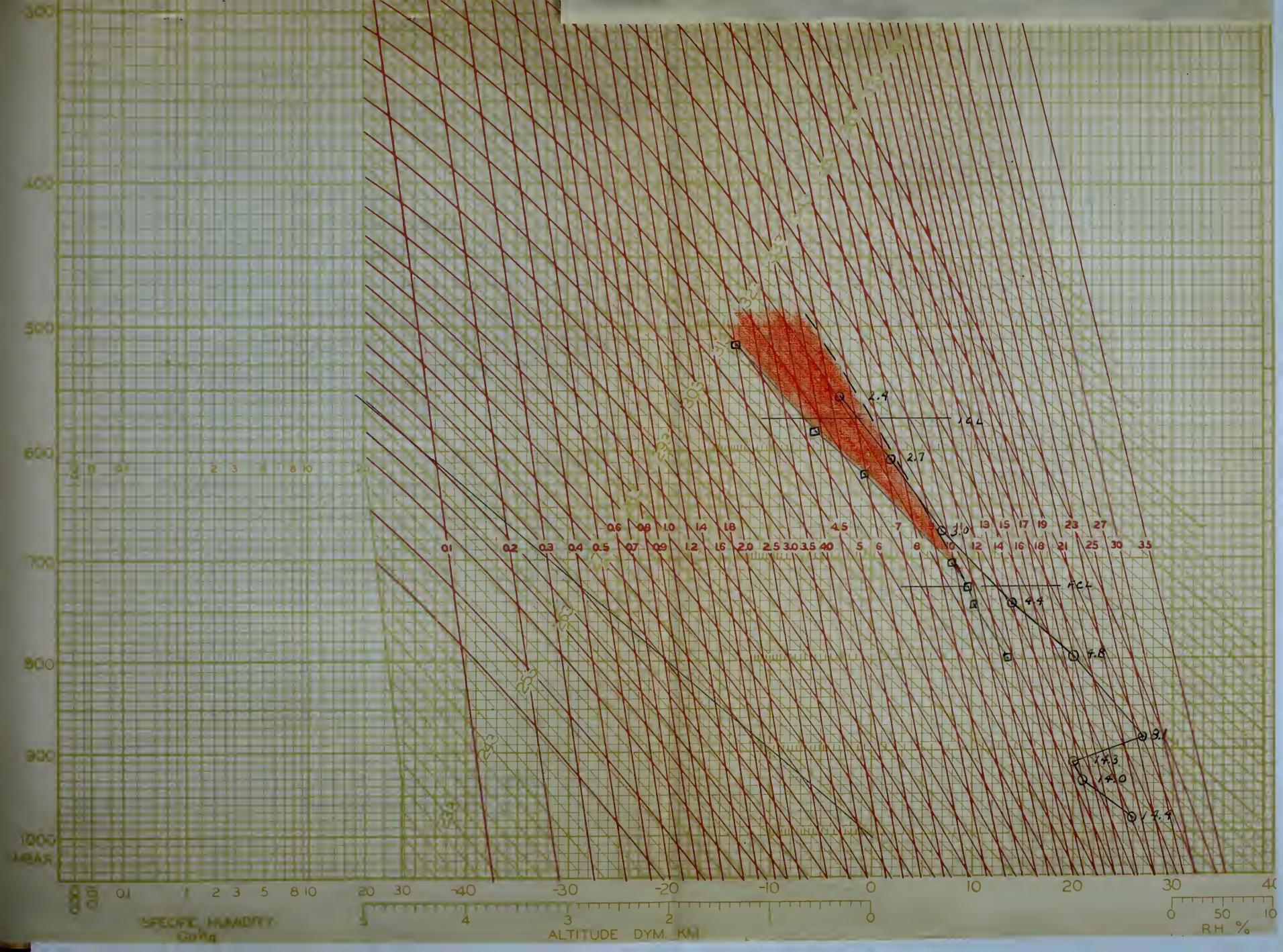
2000 meters will be required to resonant the inversion, the

salient points are each lifted 2000 meters and curve # 2 is obtained. It can be seen that the first three points are now saturated and the inversion is almost removed. It is also clear that further lifting will result in the development of a positive area extending from 728 millibars, 2820 meters, to the top of the curve. The ICL is at 574 millibars, 4780 meters. If two kilometers of lift can be provided the air which is now over San Antonio will be ready to release its potential instability, for there will be continuously increasing accelerations on a particle from 2820 meters to the ICL, and for a distance beyond that point which cannot be estimated.

The next question to be considered is whether this condition may be realized at Dallas. The computed or extrapolated movement of the front indicates that it should pass Ballas at about 0700 C.S. 29 April. In estimate of the trajectory of the air at present over San Antonio indicates that it should be overlying Ballas after midnight. In view of the movement of the front a thunderstorm, accompanied by rain and hail, should be predicted for Dallas, to occur during the early morning of 29 April.

A thunderstorm occurred over Dallas from 0500 to 0600 C.S. time. It was accompanied by hail and moderate rain.







EXAMPLE # 7. 30 April, 1937. Murfreesboro, Tennesse.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for the morning of 29 April shows a warm front just to the north of Murfressboro. It has been moving northward very slowly, accompanied by warm front thunderstorm conditions. The air masses involved are Tal and R1Pco. The afternoon map shows a large isallobaric high formed over the Mast Coast from New York to Virginia. The indications are pointing to a southerly movement of the high pressure center now situated over Quebec Province. In case this movement materializes the warm front, now to the north of Eurfreesboro, will regress and turn into a cold front. However, the over-running of the Tgy will continue, with its Vertical component of motion accelerated by the southward movement of the high and the squeezing produced by the con-Versence of the fronts to the west and north of Murireesboro.

Following the teletype reports, if available, the Murfreesboro observer could see that the front to the north was regressing and would recross his station during the morning of 30 April.

This should roduce violent thunderstorm activity, and is a

situation analagous to that in which the U.S. Akron was

lost in April, 1933.

In this case, judging from the pilot balloon runs, the trajectory of the air now over Shreveport on 29 April will

AAAAAAA TAGAA Murfressiore, Temmence. This is type I to cold from companies were advantament a decore livery the to pulmon only not young attendance now gard him all constitutions. To derive out of Jan, Jural claw sorting northeard very slowly, snoothness as were trees thunderstorm conditions. For six camera involved are Int and spices. The aftermoon out should a large landing out of the formed over the fact these from Jew 1972 to Virginity. The indications are cointing to a southerly coverage of the bight priserire center non alumated over quell'e province in team this coverage naturalists the even front, mer to be not not or Marriagenoro, will regress and thin into a sold front. Somewar, and ower-running of als Int will combines, whom has Varidasi campom ot of notion educated by the songious area and as asserted or secure of the state of the con-DESCRIPTION OF MATER AND JAMES OF BUILDING WAS TO COMPARED This should produce windows timedeserant angletic, and in a all markets analogous to that is anion the Tour added and SERIE , LINES OF PART

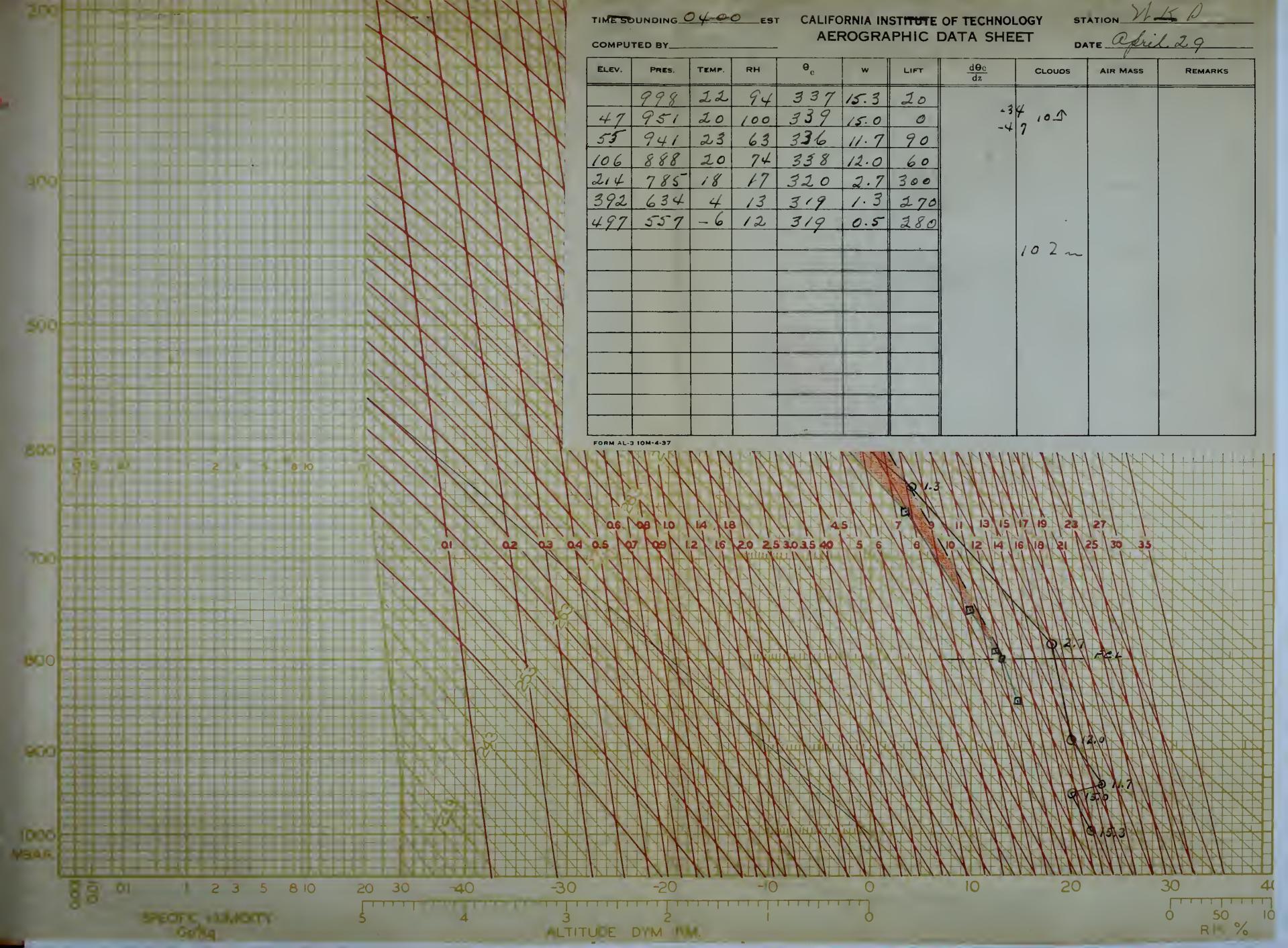
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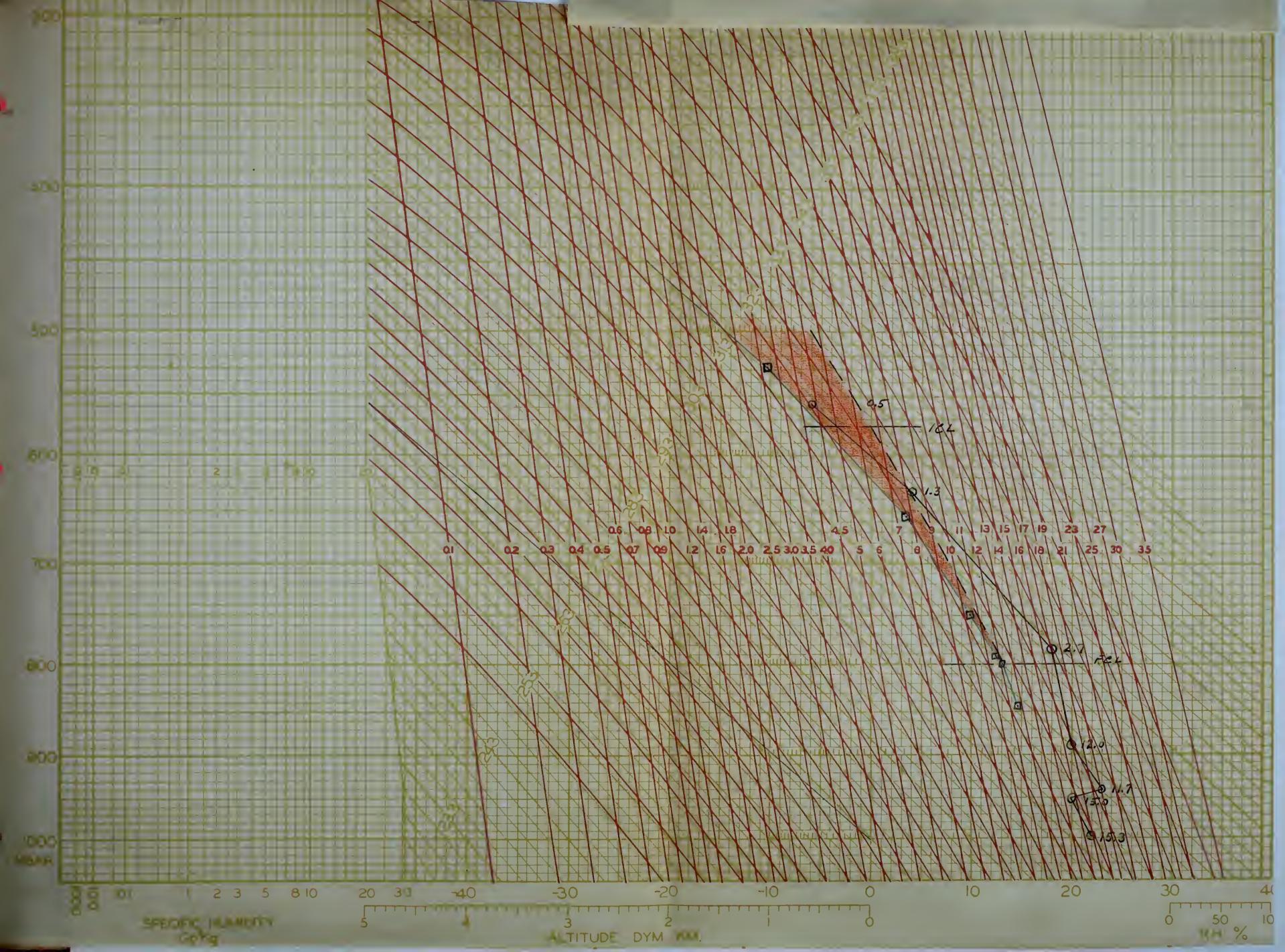
Alle Lines HE me drawstown name man with all to productive

cause it to be approximately the air which will be at the front as it returns to the vicinity of Murfreesboro. Plotting the Shrevsport serograph sounding on the adiabatic chart it is obvious that no anticipated surface temerature will produce convections to the condensation level. However, it is seen that a lift of 1500 meters will be sufficeat to release the potential instability of the air. Replotting each of the salient points of the ori inal curve with a lift of 1500 meters. it is seen that the first four point: are saturated and that further lifting will allow a particle from the second point. 800 millibars, 2000 meters, to rise alon, the moist adiabatic through that point. Followin, along this moist adiabatic it is seen that everywhere the particle will be to the right of curve \$ 2, a positive area will extend from a00 milliours. 2000 meters, to the top of the curve. The ICL lies within this area t 572 millibars, 4200 meters. A particle which can be lifted through 800 millibars will be increasingly accelerated to the ICL and for a distance beyond that point which cannot be estimated.

In view of the synoptic situation the forecaster should anticipate severe thunderstorm conditions to occur over aurfressoro during the morning of 30 April.

occurred t furfreesboro and throughout the district around
Tennesse and Missouri during the early morning of 30 April.







Coco Solo, C.Z. 15 November, 1936.

This is type # 5, cold front thunderstorm situation.

This example of a cold front thunderstorm situation is offered for the unusual values of humidity found extending to the top of the aerograph curve, and for the fact that although the positive area is not nearly as large as other examples presented, it resulted in the most severe thanderstorm that occurred over this station since records have been kept.

Consider tion of the synoptic chart shows a cold front approaching the station from the north. Naturally the front is decellerating, but by extrapolating its past movement it should pass the station during the afternoon. The air masses involved are Em at the station and the approaching mass, Pco.

From the aerograph curve, plotted on the adiabatic chart, it may be seen that the air mass now overlying the station is conditionally untable from 964 millibars, 390 meters, to 644 millibars, 3820 meters.

It can readily be seen that no expected surface temperature will be high enough to develop free convections. So the forecasters attention is turned to the amount of lift required for free convection. If a lift of 500 meters is applied to the selient points of the original curve it is seen that the air will be saturated from the surface layer to 790 millibars, 2100 meters, and that any further lifting will cause the lower layers to rise along the moist adiabatic where they will be everywhere warmer than their surroundings. If the ascent

Code tole, C.S. In sold from the the streeten.

This example of a sold fromt temperature astunction is offered for the uniquely values of hashifty found establing to the top of the menograph curve, and for the fact that as a large sections; the positive area is not mainly in large as other assumption presented, it resulted in the most corner temperature that occurred over this station since records have come aspt.

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From the serograph curve, plotted on the solitantic court, it may be seen that the air take now everlying the station is countitionally anti-ble from 160 military, 700 matery, to fee at Libery, 3820 meters.

It can readily to soon that so espected serves temporaries with a bigs enough to divelay free compression, we shad forecassion abturnation is turned to the anount of life required for free convention. If a lift of cod maters is applied to the equiron to existent outset it applied to at a equiron points of the configural outse it is seen that the air will be determined from the nurface input to 767 military. All of the first and fifting all cause the lower layers to rise along the units affairs that cause they are layers to rise along the units affairs that the same the another between the state the another serious ties will be averaging the same that the another serious ties and the everywhere estimate their extraordings. If the another because

curve of a particle leaving the saturated layer is plotted it will show a positive area extending to the top of the ascent curve.

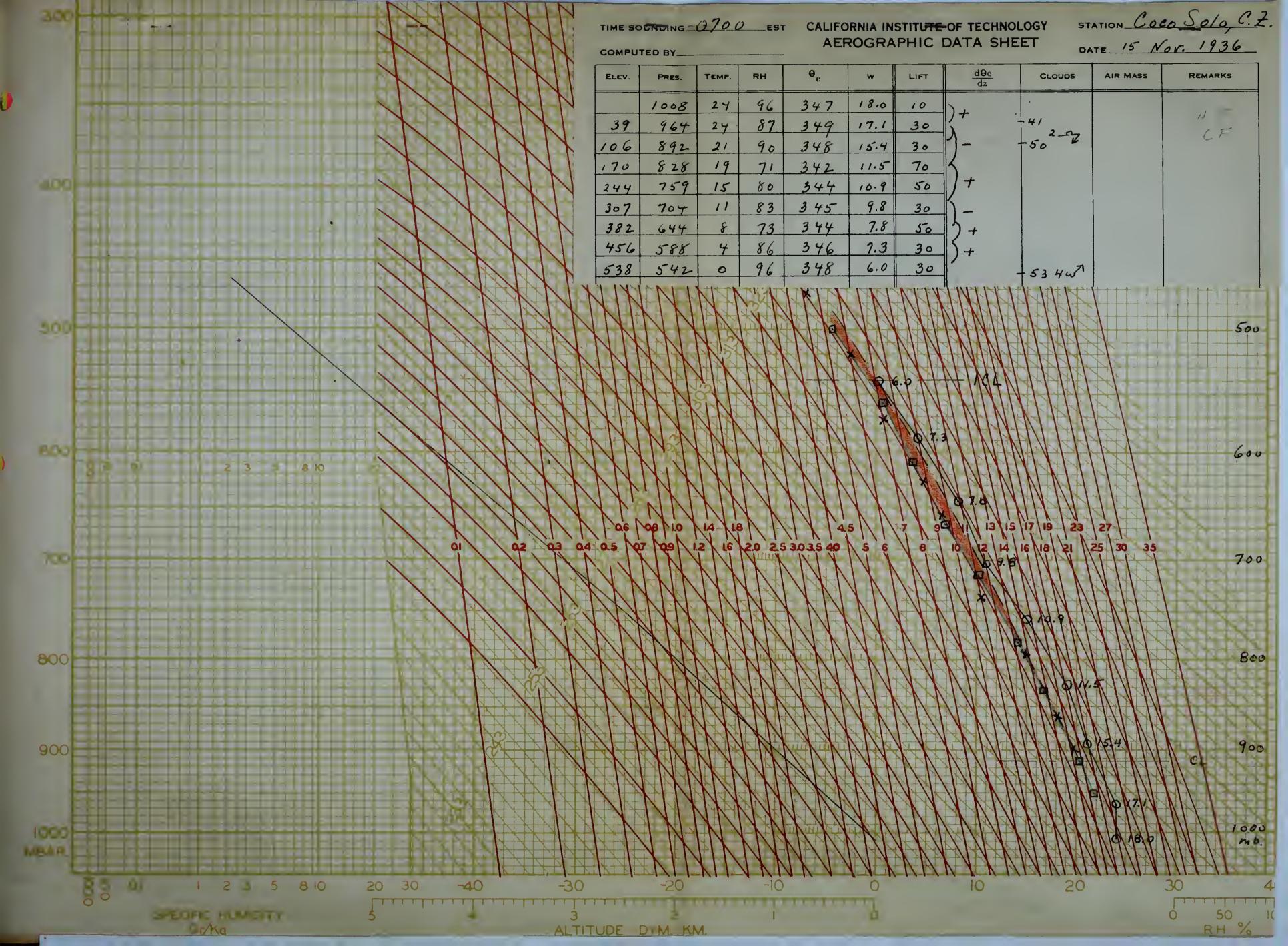
If a lift of 1000 meters is assumed, and the lifting procedure carried out, it is found that there is practically no increase in the positive area; this result could have been foreseen if it had been noted that the whole curve is practically in neutral equilibrium for the saturated condition, since the total change of the equivalent potential temperature over the sounding is but seven degrees.

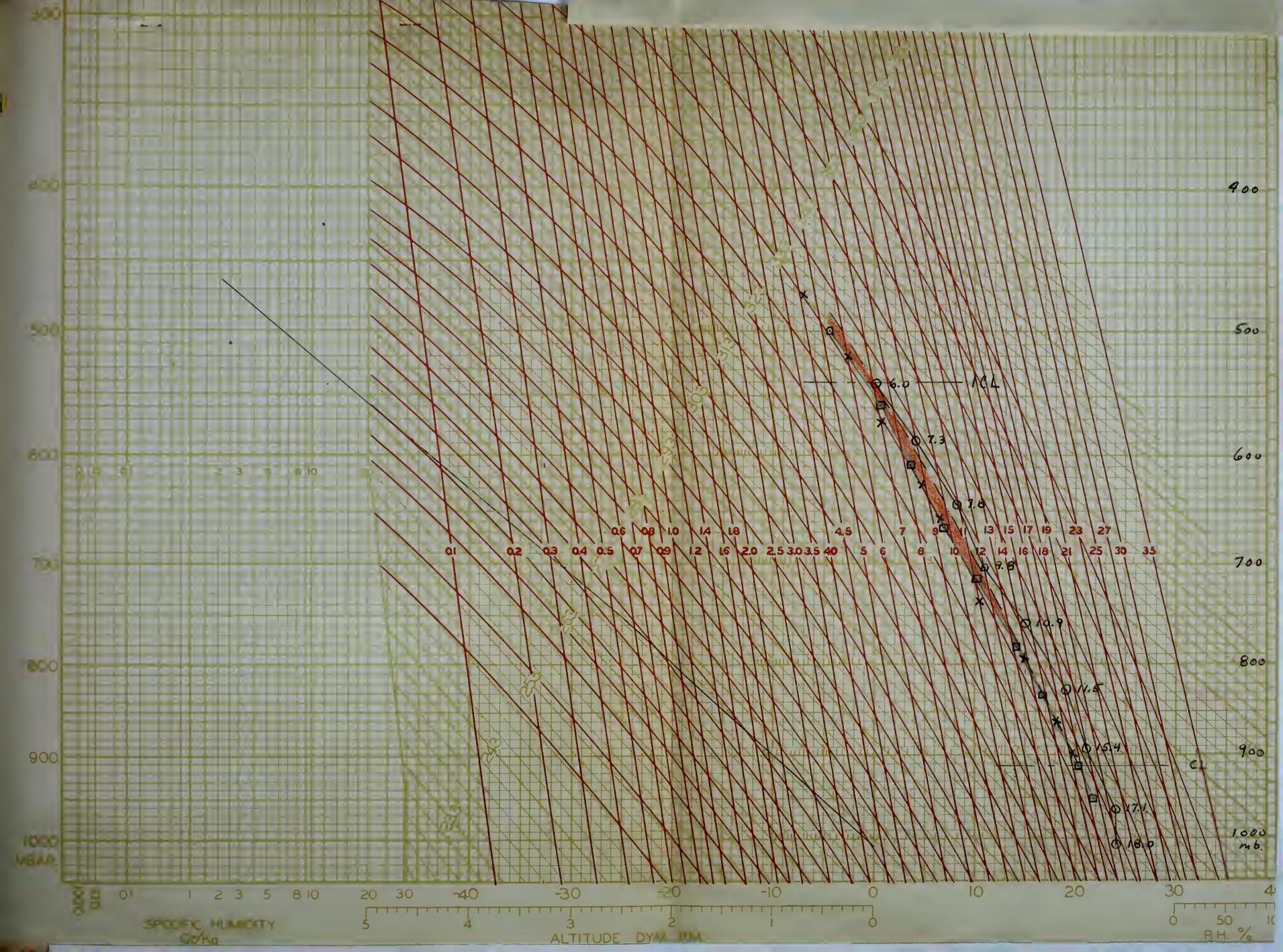
Considering the adiabatic plot it is seen that the ICL is within the positive area at 542 millibars, 5280 meters.

There will be continuous acceleration on a particle from 792 millibars, 2100 meters, to the ICL and for an undetermined distance beyond that point.

It is believed that a thunderstorm would be predicted by most forecasters in this situation. However, it is not believed that many would have anticipated such a violent thunderstorm as occurred, undoubtedly due to the large quantity of water vapor present throughout the air mass and to the possibility of a sharp falling off in water vapor at levels above the sounding.

A most violent thunderstorm, accompanied by 3.15 of rain, occurred over the station at 1710.







Scott Field, Illinois. 5 May, 1936.

This is type # 3, warm front thunderstorm situation.

The synoptic chart shows a somewhat complicated frontal system about 130 miles southwest of the station. It will act more or less as a warm front and is moving very slowly not theastward. The station lies in RPco under the warm front, with Tg2 over-running. Inspection of the sounding shows that the frontal zone is at an altitude of approximately 2000 meters.

An inspection of the upper winds shows that the air now at Oklahoma City is the closest approximation the forecaster can obtain to that which will be over-running the station during the forec st period. Examination of the Oklahoma sounding shows that the air up to 2580 meters is in neutral equilibrium for the saturated state but conditionally unstable above that point. However, since the  $\theta_{\rm E}$  is only reported to the nearest whole degree, it is advisable to plot the sounding on the adiabatic chart and lift the mass 1300 meters, which is sufficent to saturate the apparently neutral hayer. Upon performing this operation it is found that a slight degree of instability does exist above the third point from the surface.

t this stage another factor must be considered; the forecaster is dealing with a warm front, and although convergence may be present in the old polar air beneath the front, the flow in the warm air over the front is anti-cy-

Scott rield, filthois. I hay, 1886.

This is type 0.3, were front themservous situation.

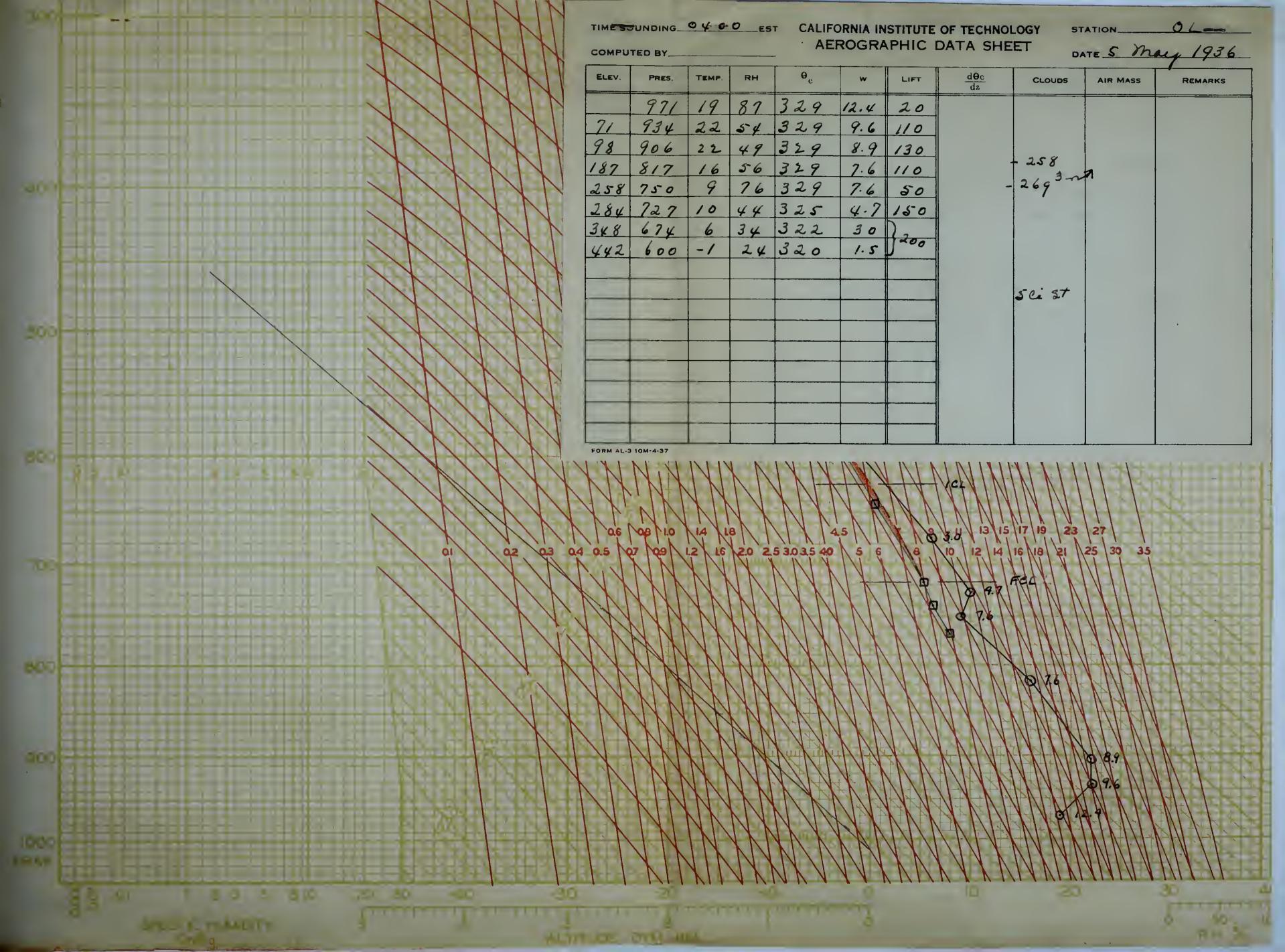
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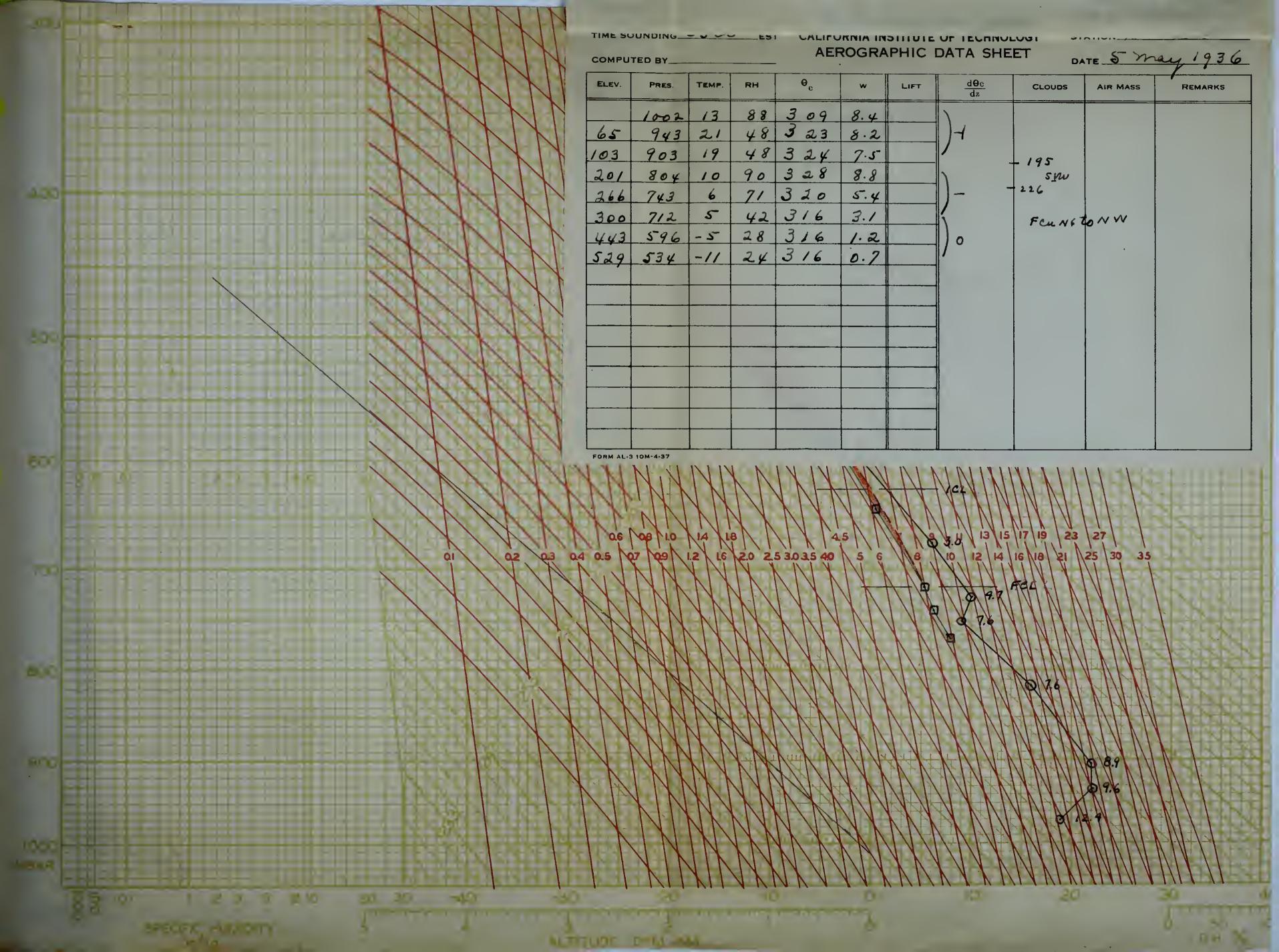
An inspection of the upper winds shows that the six now at most an adapted the adapted at all above the adapted of a standard the standard of the contains the standard of the forest at a fact and the standard of the following the standard of the obtained and the standard of the standard at a selected the standard of the selected and the standard of the selected the above that soint. However, atmost the  $\Theta_{\rm g}$  is only reported to the nearest whole contains the  $\Theta_{\rm g}$  is only reported to the standard of the selected to the search whole contains that the selection is sufficient to entire the standard of the standard is selected agent the standard of the standard and the standard of the section of the standard and the standard of the section of the section of the standard of the stand

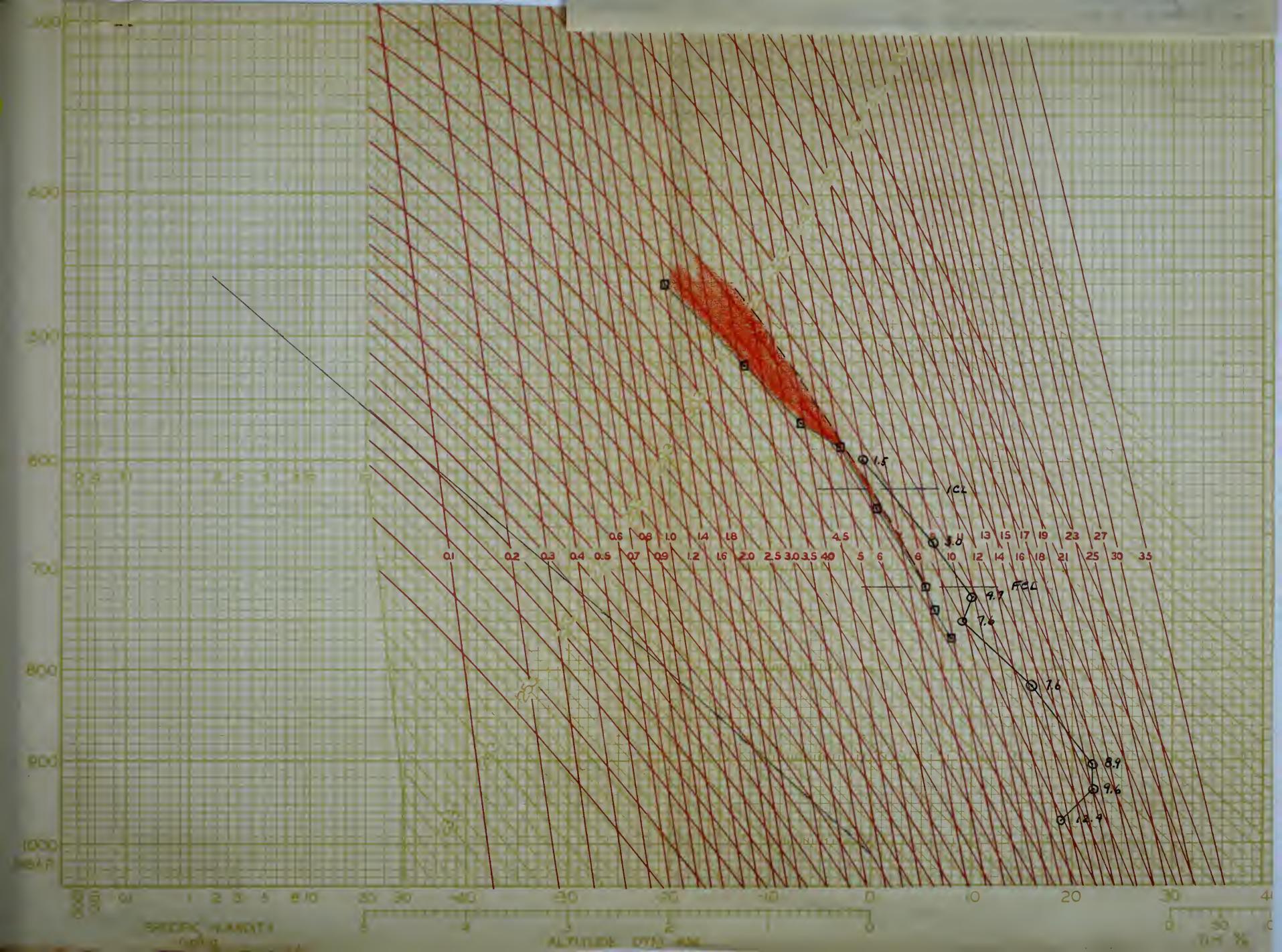
At this study another fuctor must be considered; the forestance is doming with a sure front, and although comvergence may be present in the old polar air beneath the front, the flow in the warm air over the front is sailingclonic and therefore some divergence is present. This is previously mentioned, will increase the instability of the Tg<sub>2</sub> air after it has become saturated and its conditional instability realized.

This factor should be the decisive one and a mild thunderstorm forecast for the station. The curve has been drawn
for the Tg after being lifted 2000 meters, this being approximately the height of the front over the station. However, in
arriving at the thunderstorm forecast, it must be borne in
mind that instability was developed after a lift of 1300 meters and that the rising particle has been accelerated, before
reaching the ICL, for 700 meters more than shown on the adisbatic chart, or a total distance of 1870 meters.

A mild thunderstorm occurred over the station at 1400 E.S.T., accompanied by light rain.







SYMPPTIC SITUATION 31 March-2 April, 1836.

This situ tion is presented as an example of the manner in which a deep low pressure area in the nocky curtain states will induce a flow of Tg. ir to the east of the Rockies and produce widespread thunderstorms throughout the distincipal Valley and the Southwest.

Although at the surface Can Antonio is in the Peq air, the cloud crift is from the routh ast and several stations in the parties from their 1 april to the north report alto-curulus from the south est. This MANUFACTURE BOY DO LET THE PARTY BAT would suggest over-runding of the c by T ir, a lact conin rack the investment that the firmed by the sounding at San Antonio, which shows a large increase of  $\Theta$  = 1 t 980 peters, from 3120 at the surface to 332° at this point. The structure from this point apward is MA THEORY CAS IN MAIN From CAS SOUTHWEST IN conditionally unstable and the values of the lift required sho that in additional 1000 meter lift will be sufficient to DESCRIPTION OF THE PERSON NAMED IN release the conditional instability of the air. Since the cloud drift has indicated this to be taking place, thunderstorms are to be expected in eastern central Assissippi Valley during the next twenty four hours.

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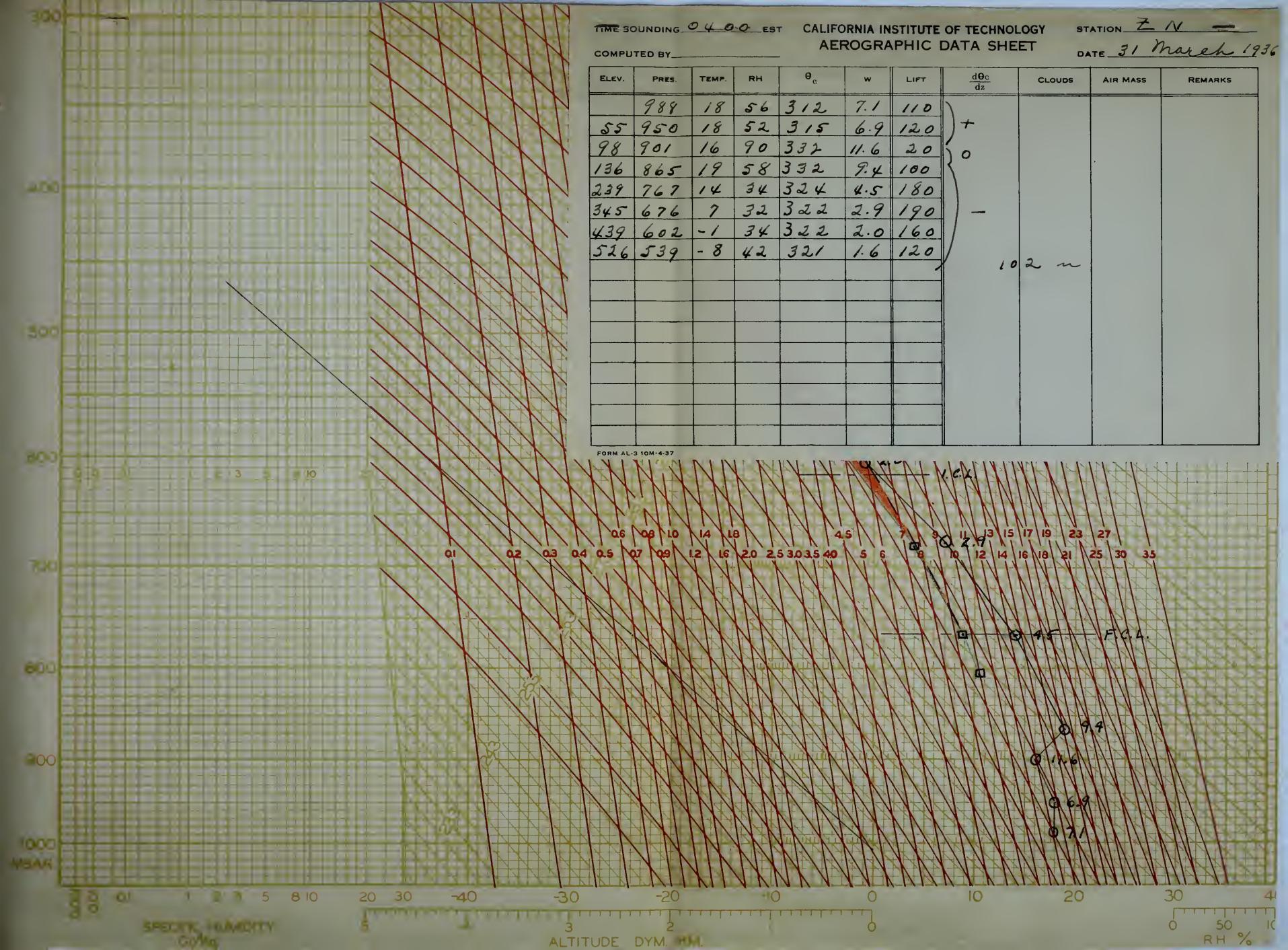
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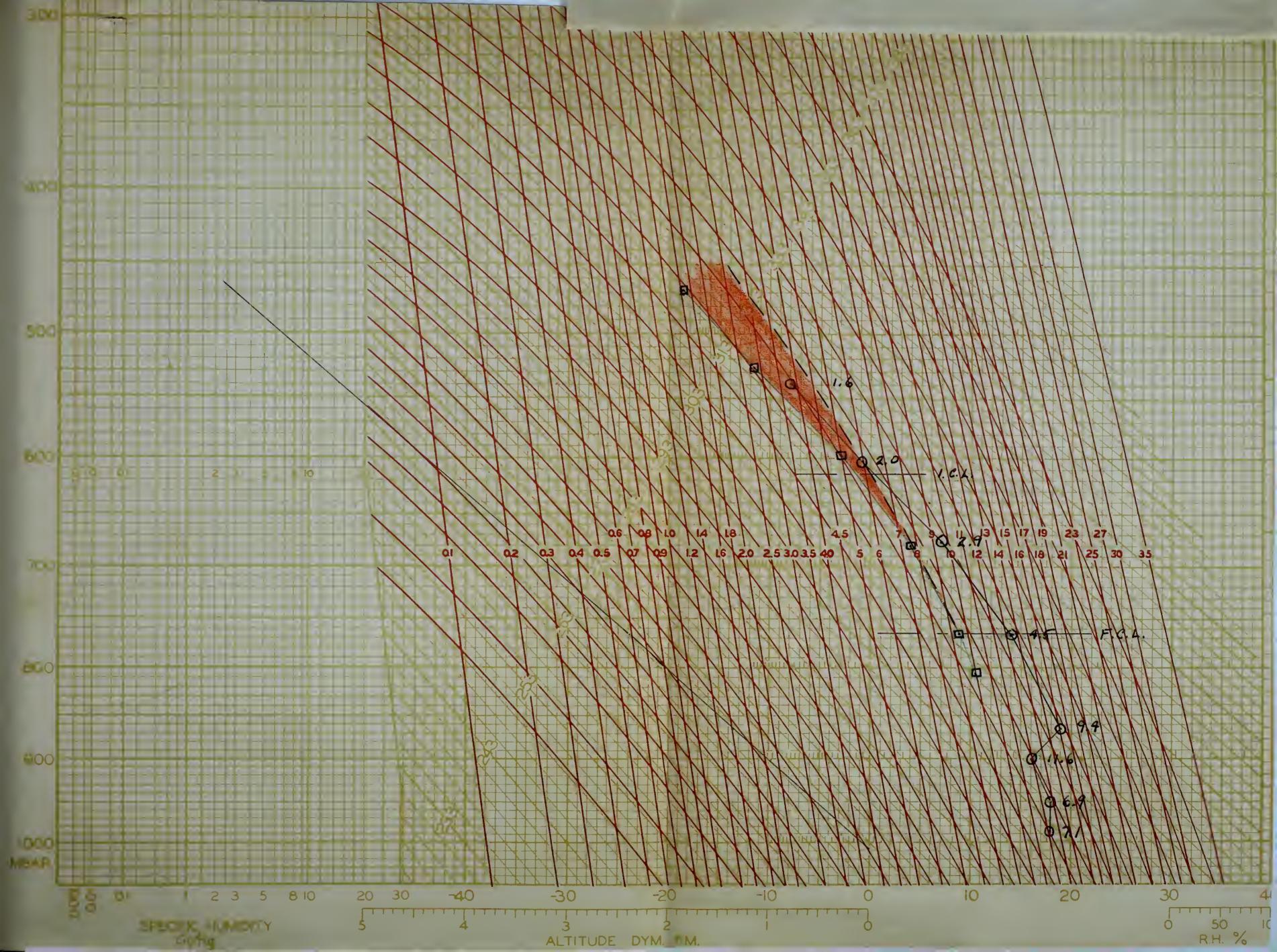
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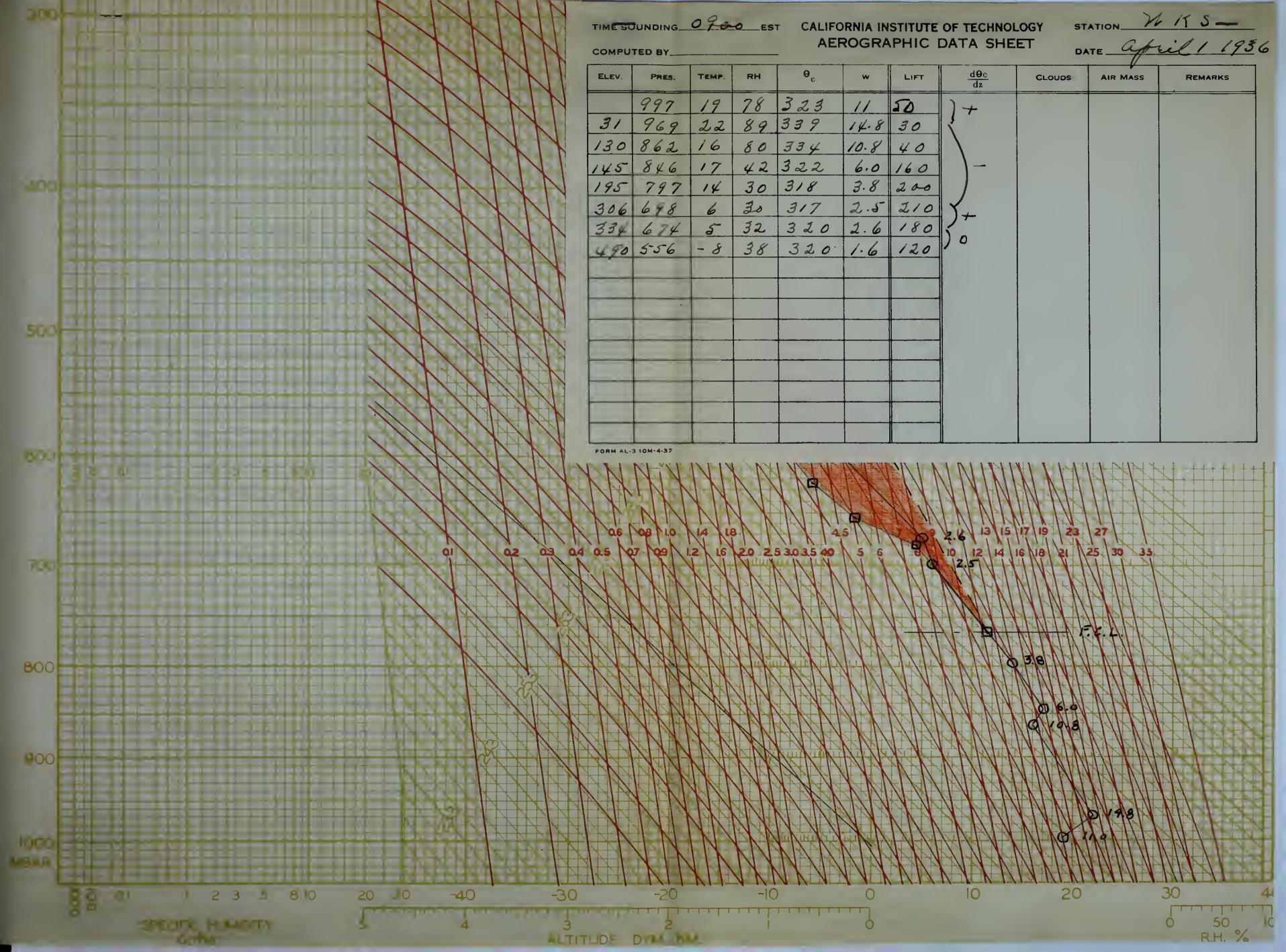
The map for 1 April shows that the expected development has taken place, although the thunderstorms did not develop until 2100 on 31 March, and none are reported in western Oklahoma. This is probably due to the fact that the air over-running the front in vestern Texas is oPp2 which is not unstable. The wave located in e stern Texas on the 31 March map is now centered in northern Mississippi, with large negative tendencies to the northeast of it, indicating a deepening with a consequent southeasterly movement of the cold front behind it. The aerograph sounding for Shreveport for this morning definitely shows that Tg air with considerable conditional instability is moving northward over the warm front.

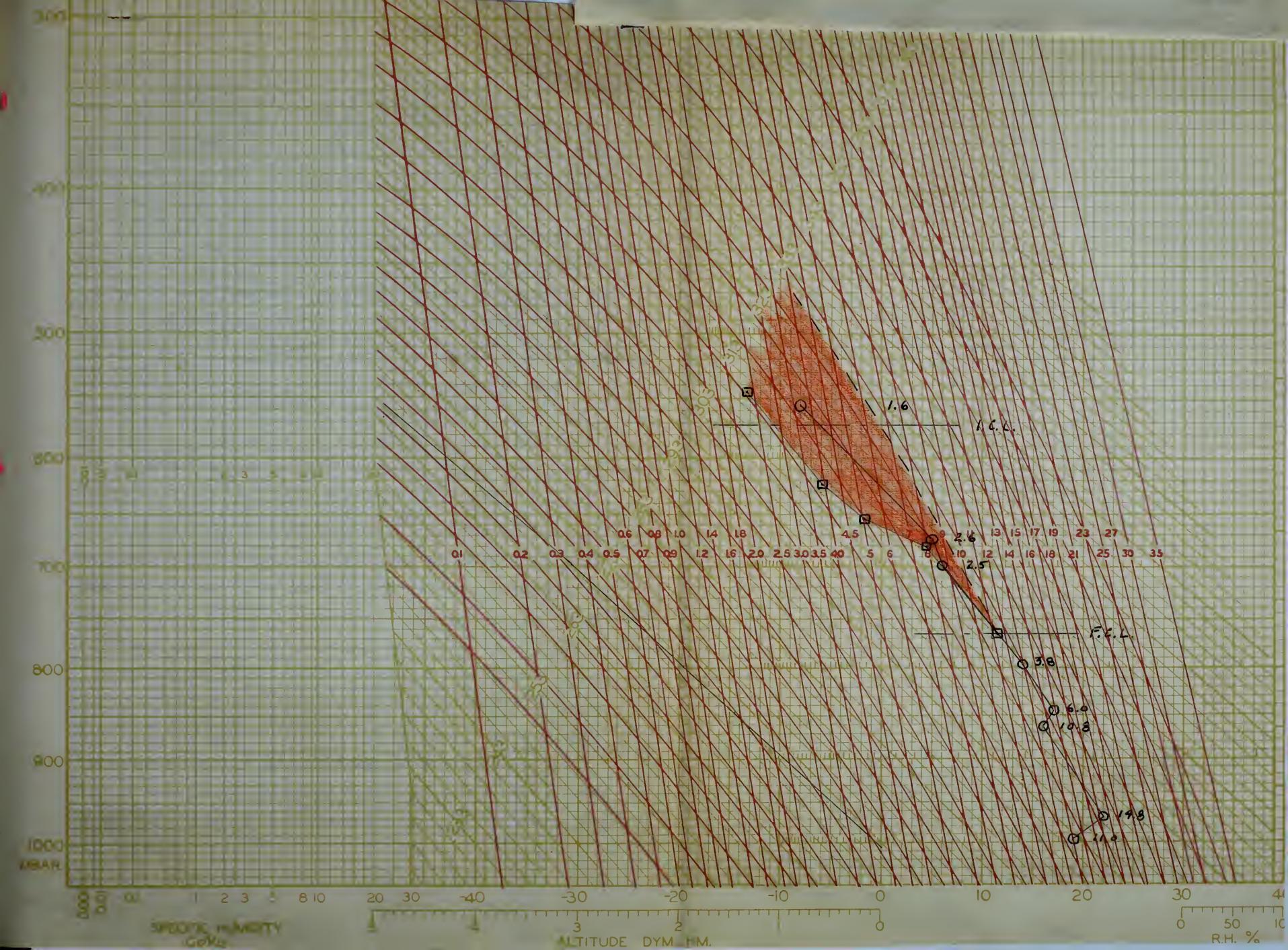
The map for 2 pril shows this development to have taken place; the southern section of the front is now in the Gulf, and an easterly movement indicated for the entire front. During the period from 0300 l April to 0800 2 April the thunderstorm area moved to the eastward but did not decrease in size; in fact the intensities increased due to the front and instability.

The anticipated movement from 2-3 April can be expected to remove the T<sub>S</sub> air from the continent and the map of 3 April shows the entire United States, west of the Acckies, invaded by Fc air.











SYNOPTIC SITUATION 25 April-23 April, 1936.

This situation is presented to illustrate the manner in which a warm front ith considerable thunderstorm activity is frequently found on a quasi-stationary front lying just east of the Rocky Mountains.

The 0800 map for 25 April shows an almost stationary front separating  $Pc_5$  to the north and a mixture of oppo to the south, running through Colorado, Kansus and Nissouri, and a arm front separating the Pp air from RPc3 located approximately along the Mississippi River. The predient in Texas and Oklahoma shows that air is being drawn up from the Gulf, a fact which is confirmed by 25 to 30 knot winds in the upper air. Unfortunately there is no sounding from Dan Antonio on this date to verify the inclusion of  $T_6$ . The upper winds in the eighest levels are from the north and northwest, indicating that the air sloft is oppo, which has approximately the same temperature as the  $T_6$  but contains very little moisture. The presence of a dry layer over a moist one, without the presence of an inversion, produces a high degree of instability, conditional, due to the rapid decrease of  $\Theta_E$  with altitude.

Thunderstorms have already developed along the front in Kansas, Oklahoma and northern Texas by late afternoon on the 25th. The situation has become more obvious on the 0200 map for the 26th. The sounding from an Antonio shows the presence of air approaching the characteristics of To, which will be rendered unstable by a 2000 meter lift. No movement is in-

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dicated for the front except in west Texas where large positive tendencies indicate a northerly movement.

Thunderstorms have developed all along the front by 2000 26 April, and the 0800 map for 27 April shows a well developed with front through Kentucky, "issouri and southern Illinois.

The sounding from Chreveport shows that the air flowing north over this section is conditionally unstable from 1500 maters to the to of the sounding and requires only a 2000 mater.

Lift to produce instability. The warm front thunderstorms continue throughout the day and scattered air mass thunderstorms are reported along the Gulf Coast.

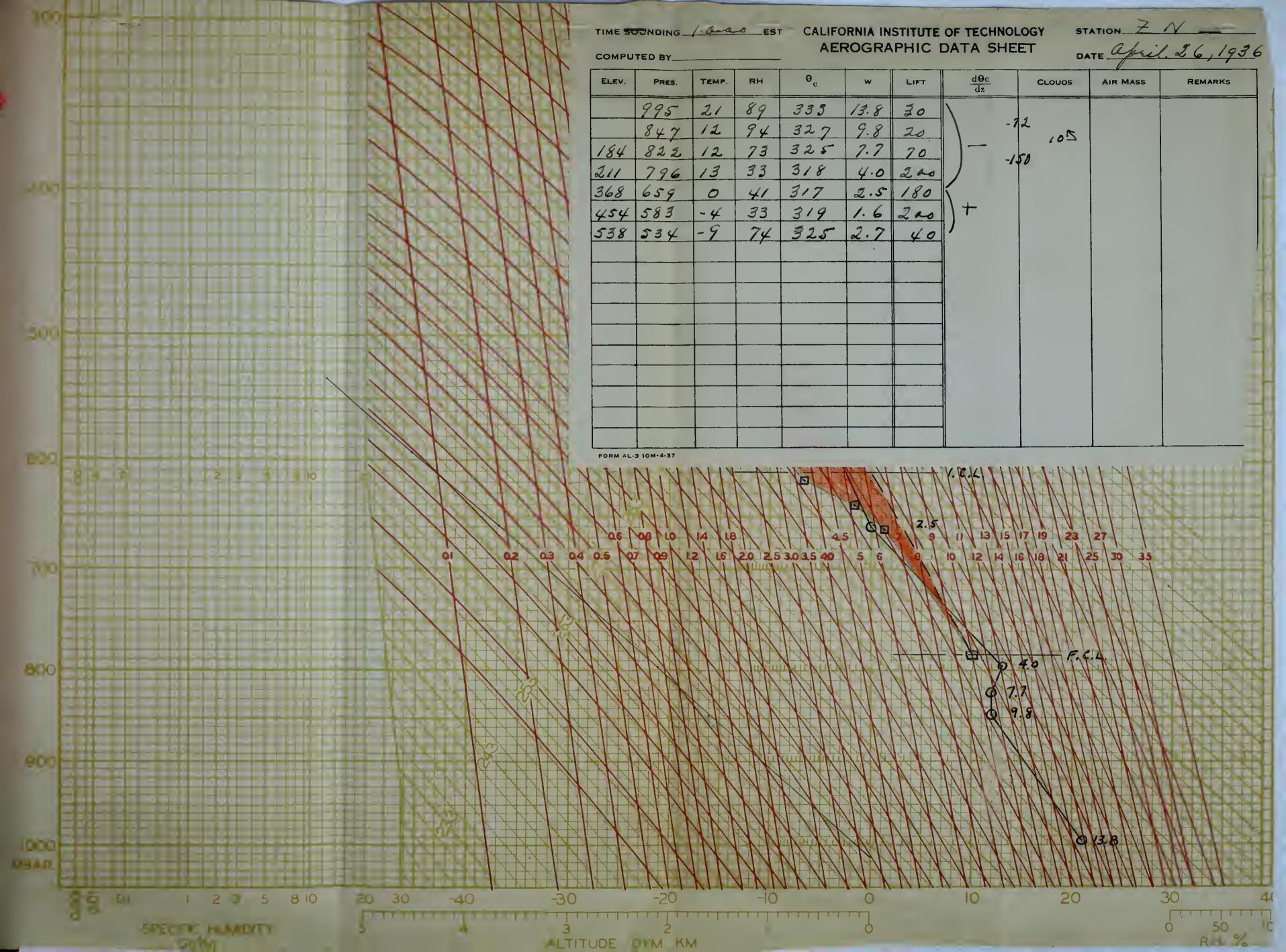
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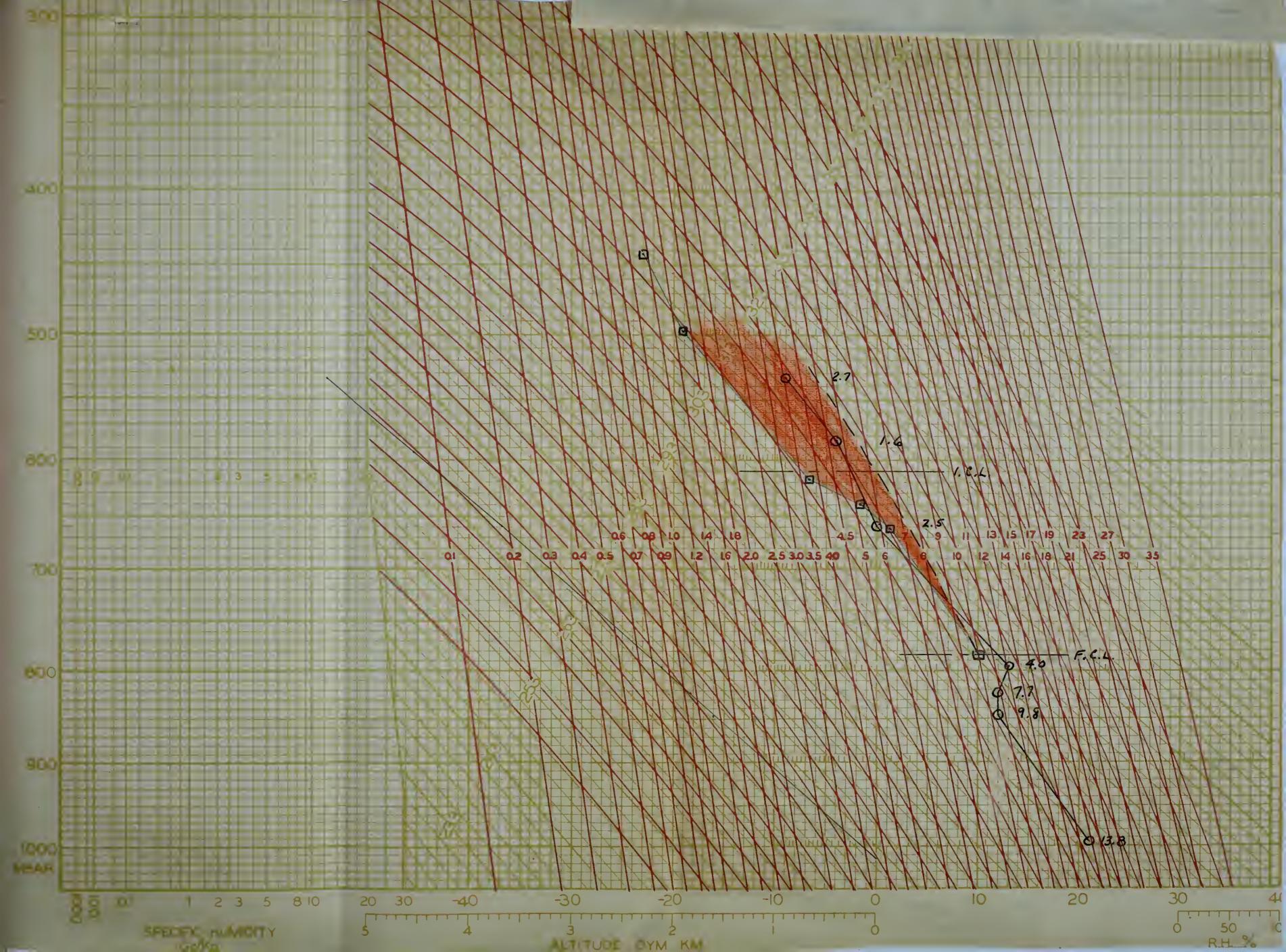
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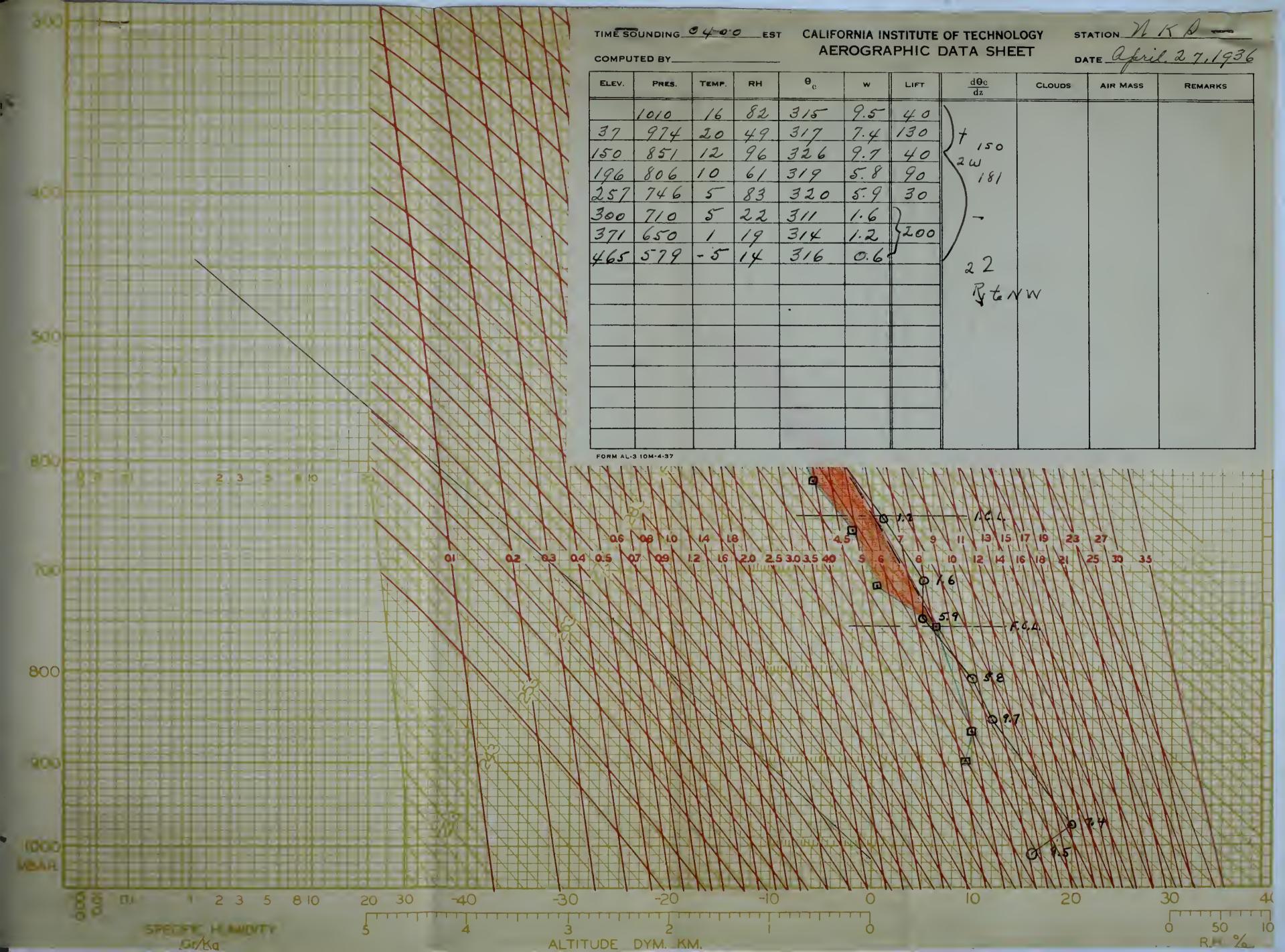
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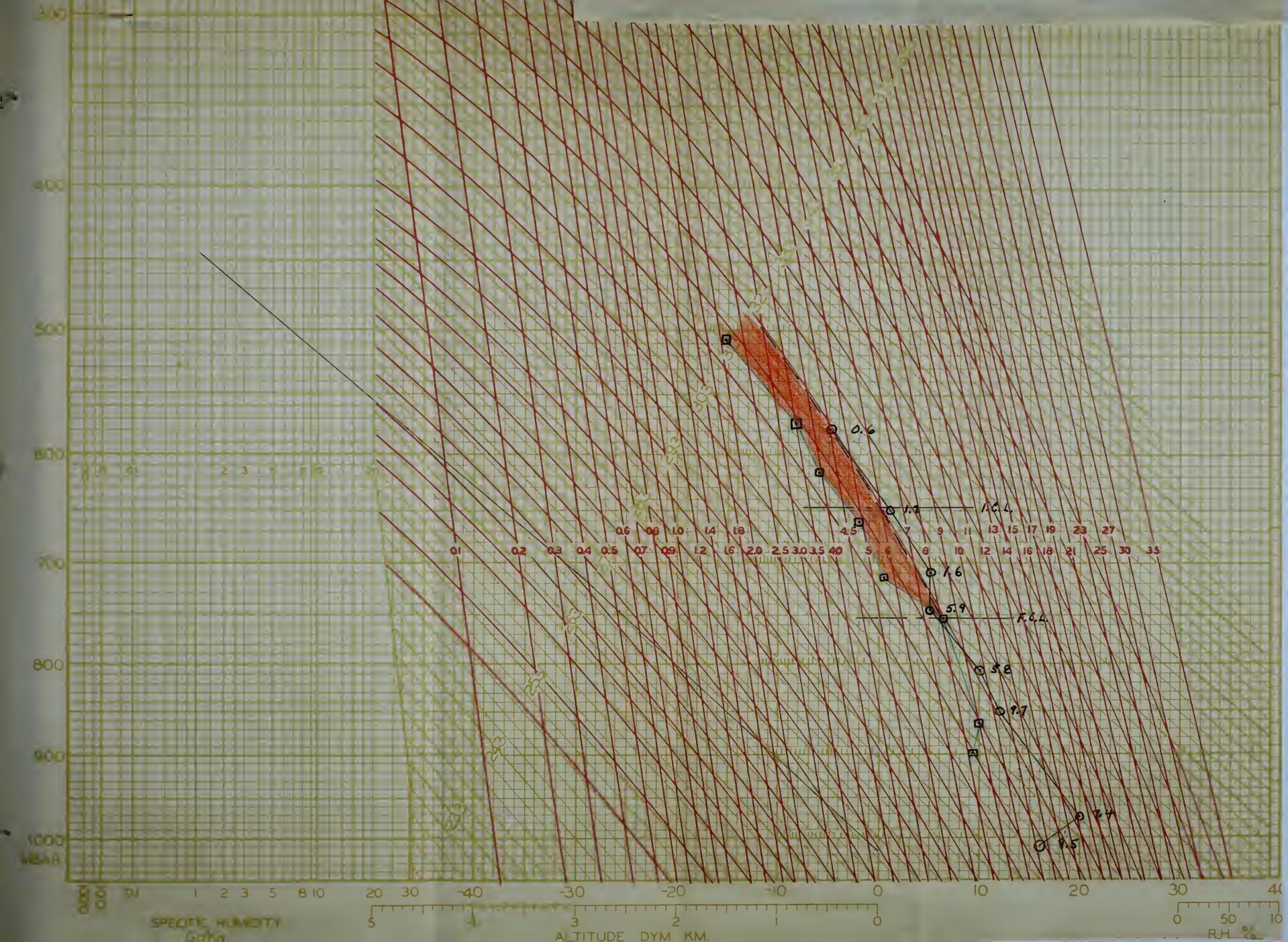
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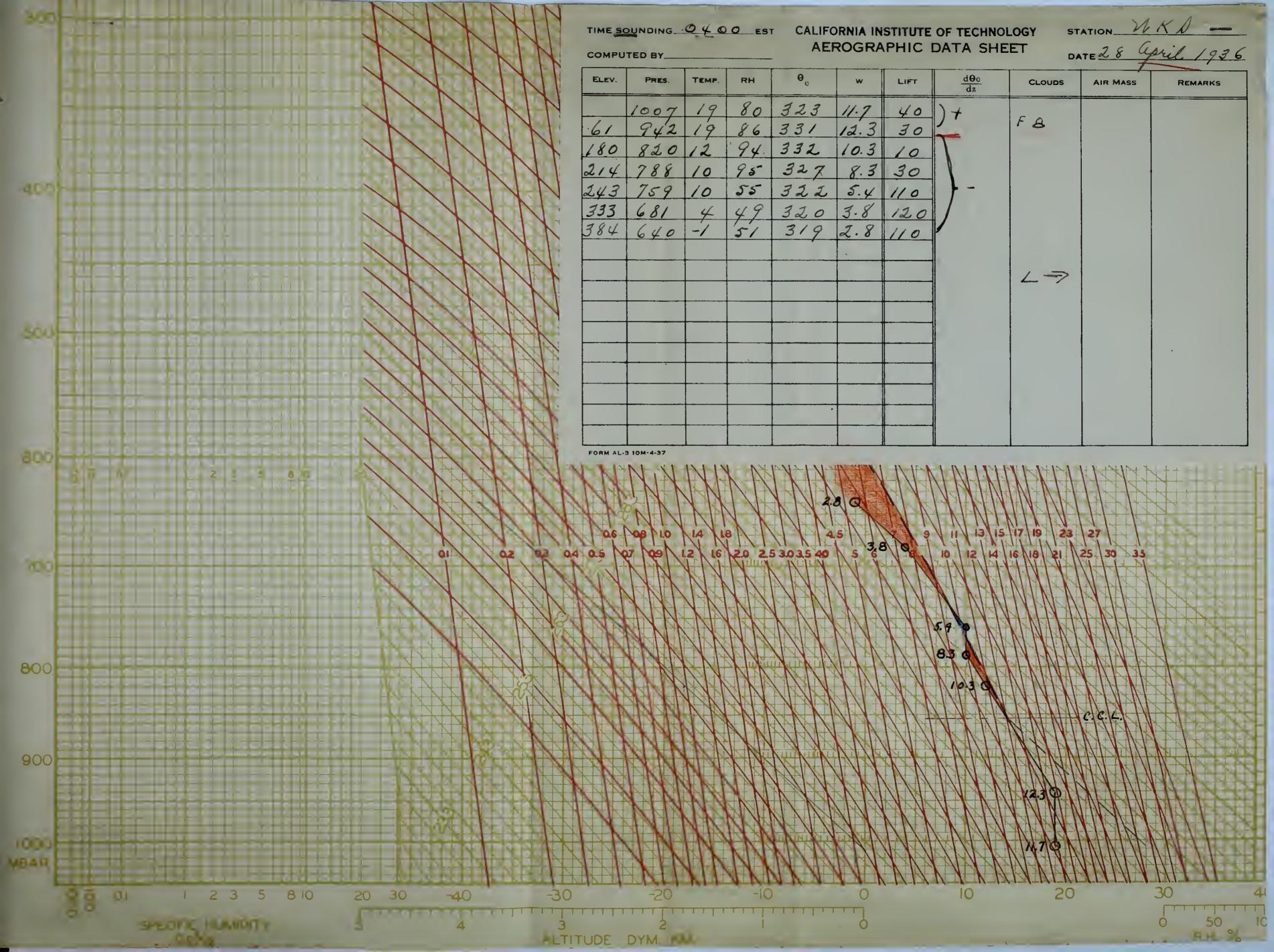
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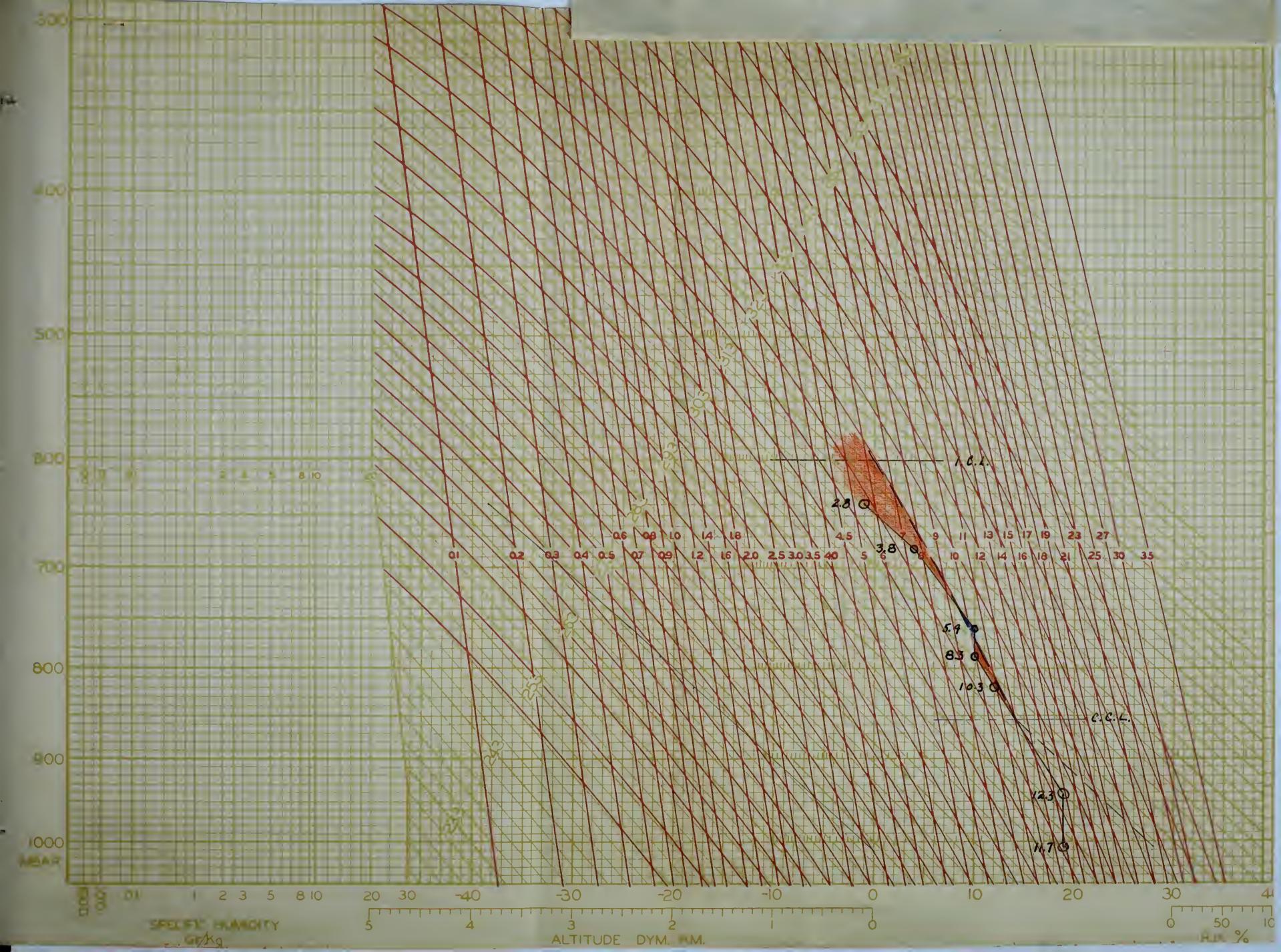












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## SECTION THREE

Pre-frontal thunderstorms produced by a convergent field of motion.

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This type of thunderstorm is liven a section in the original classification solely because it has frequently been referred to by others. It is our belief that this designation could as well be; produced by a lift, produced by an orographic obstruction, produced by insolutional neuting or produced by a combination of these and convergence.

known to exist and can be shown, on a teorological carets,
to have a decided effect. Ho ever, to designate a type of
thurserstorm as initiated by convergence seem to august
that a measure of such convergence can be used to say,
"This such convergence will produce so much effect." To date
there is no meant while with which to measure convergence quantitatively, in practical forecasting.

There is no definite point where it can be said that a presental thunderstorm ceases to be produced by lifting and is produced by a convergent field of notion. In the rice cases of thunderstorms in the cold air under a warm front the cause may just as well be laid to insolational menting as to the effect of the convergent field of motion.

There are undoubtedly thunderstorm produced which can

## STUTT PULTOUS

The frontal thunderstorms produced to a convergent

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referred to my others it is our belief that this does not.

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the course may just as sell to laid to instinctional souling.

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There are unfoundedly thundersome promper rules and

not be explained on the basis of any one measurable factor, several factors may have contributed to the final impulse which released the potential inst bility. If, as suggested by the title of this thunderstorm type, there is frontal activity present then there is certainly lifting of the air into which one air mass is intruding, in the case of the cold front, and there is also vertical motion in the cold air underlying, in the case of the warm front. There this lifting, or vertical motion, initiates is no more and no less intangible than the amount of convergence present; but it too has its effect in the production of a thunderstorm.

If one is in doubt as to the exact cause of a thunderstorm it would appear that calling it a separate type, produced by an unmeasurable, intan ible cause is not wholly
justified.

The types listed in sections one and two, together with variations in expected position of development which may be attributed to trajectories from the point of inception of convective activity to the point of realization of the thun-erstorm, seem sufficent to explain the thunderstorm phonomenous with which the forecaster can sufficent deal.

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Trajectories of thunderstorms.

The trajectory of a thunderstorm is of importance to any forecaster, but it is of particular importance in aircraft operations, especially on scheduled ir lines.

Any thunderstorm, no ratter how produced, is contained in one air mass and trivels with the general flow. In this manner convections which are produced in one are, and maintained, may produce or continue the derstorms for from the point of origin. Thus the general trajectory of thanderstorms may be estimated from the upper wind velocities obtained from pilot balloon soundings. From the force sting point of view anowhedge of thunderstorm conditions existing in an area from which the upper winds may carry them to the forceasters station is of importance in arriving at a force at. Similarly local topogramy may favor the day lopent of thunderstorms, in certain situations, which will be carried to the station in the general drift; the classically occurrence of summer of termoon thunderstorms near Denver is an excellent example of this condition.

The extra-tro ical cyclon it. an oren era sector lives an excellent example of ossible thunderstorm trajectories.

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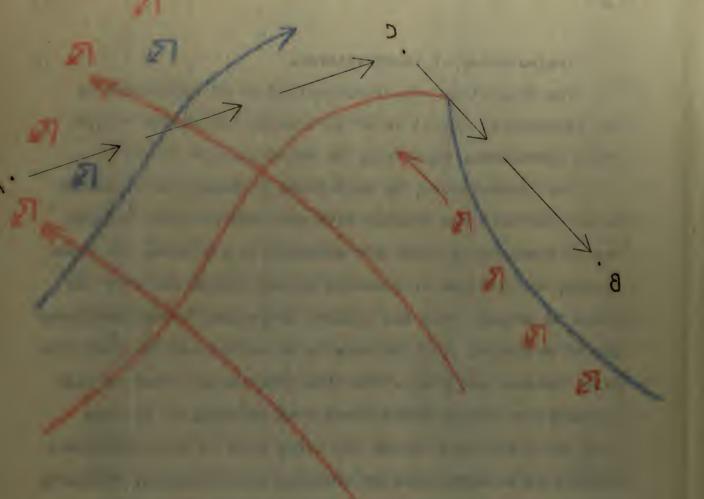
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regard operations of military nature the question to the tracks to avoid thunderstorms is to be answered by convenience or necessity; but in the case of scheduled air line mations such flight paths on and should be the consider the of the displace of the place of form, it itude, probable at and velocity of the thunderstorm, it is the flight of the plotted to avoid the are made the flight of the condition similar to the diagram wave, when it is desired to crear an alreast from point to , should lead to a decision to order the flight to follow the flight path 1.-C-1. In this flight he would fly at a surfacently low altitude, topography permit-



reports operations of military nature the converses of a compared by an expension of alternates at a compared by an expension of alternates at a compared by an expension of alternates at a compared by a compared

ting, to fly under the warm front to point C. During daytime he could go ever the top, night flights should go as indicated. In this manner he avoids the thunderstorms in the warm current over-running the warm front, and such thunderstorms as may be met in the cold air will be widely scattered and of slight intensity. From B to C he is flying behind the cold front and in this manner avoids the cold front thunderstorms, which are the most violent and may be precically continuous over a long front. In this regard it is well to remember that warm front thunderstorms will be high level disturbances while cold front thunderstorms may extend from comparatively low levels to heights above the maximum altitude of present day aircraft.

BUTAT PURSUE OF FULL CENERABILITY TO BE TO BY MAN HARMA

In regard to the most probable hours of occurrence of thunderstor s a vice vari nee is to be found depending upon the various types, and the terrain over the they such . lind are s or sea. Fout I thunderstorm my occur to my time of the day or night since their remation is independent of the temperature of the surf color is a function of the povements of the air master involved. If my unity, a contal thunderstorms should reach their ackinum intensity carin, the might, due to atempening of the large rate of radition I couling from the top of the cloth I yer. However, this effect could scarce, be noticeable in cold fromt the, since it would be right in the ortion to their original intensity. The mare fromt to understors, on the other hand, my or intensified, or even initi to by rainticall ecoling. Ore, relical than records the accept to hear, but they are abre frequent during the late afternoon and avening when convections due to surrice he ting assist in their levclume no; at night a rainly ouron; flor is required to overcome the countain are so erect and utill produce to under-965 9.

convective thursders activity, due to insolutional heating, is limited to the late afternoon and evening, over land area, since the forces which produce them are a maximum at that time. In fact these forces disappear at night, although the thursders are a maintained for some hours

In causes to the most probable house of occurrence of ability paintegate lames and all strangents and a second-particles. the region bound of the beauty and when the outers and Line of the or our invested Linearest and we work had the of the day or night above their remailed as job and TO STATE OF THE PARTY AND THE were any of the the states herebyed. It was been a reserve at Municipalities about room tools from themself andre will refer to the to a commencial of the latter with a real of the latter them towers the court of the others were necessar, this said a south files a me widehalton at the time faces one the after it would be salph to represent or make or know it works DESCRIPTION OF THE PARTY OF THE wanted the failure or receipted over the subtlement of The plant upon the traction with the amountaining landings are to principal for specification which and contract Assembly when the party while allows in Arrival Performs Applicated by any descriptioning hards warm of brillager of outl garde cities a doubt do streemed. -name of desired; have not desired adaption of hearth ABMINISTE.

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observations show that air mass thunderstorm activity over the oceans has a maximum during the oral, sorning hours and is a minimum during the rapid of the oceans has period of the mass of the control of the development of nocean are instability to radiational econing of the upper air, while the marked hours retain their product attending constant the period of the presence of the matter authors to the product a temperature of the product attended to the instability.

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undoubtedly 1 ad to a change complete knowledge and understands of thund returns, disc in the rest a joint, or case the activity outside for above the neighbors now remained by eraps on soundings. Me court to forest us to the type of precipit tion or intensity of the unmark torm can be made so long as the shape of the curves above the limit of the market proph sounding is a letter of conjecture.

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## SULTARY

Since many of the ideas involved in forecasting thunderstorm development are sidely southere the outhout this paper, it has been deeped avisable to collect note of the port at in an outline of augustud procedure.

- 1. Deferring to the synoptic chart, determine what air masses will be over the at tion caring the forecast period.
- 2. Considering the or jector, of the air, plat the soundin wich most rearly approximates the air rase expected and
  determine the temperature required to produce true ections,
  and the list measure if prographical tisting is possible.
  Estimate two probability of the required temperature being
- 3. If my frontal plants to expected suring the forecut period, deter inc the ground of lift required to roduce instability.
- the canage which will take place in the structure of the sir caring the forecast period and their effect upon its stability.
- 5. Asving arrived at a decision regarding the type of the conterve area, and its identifier on the additionable chart, sections to be intermity of the transfer and type of precipitation to be exacted.
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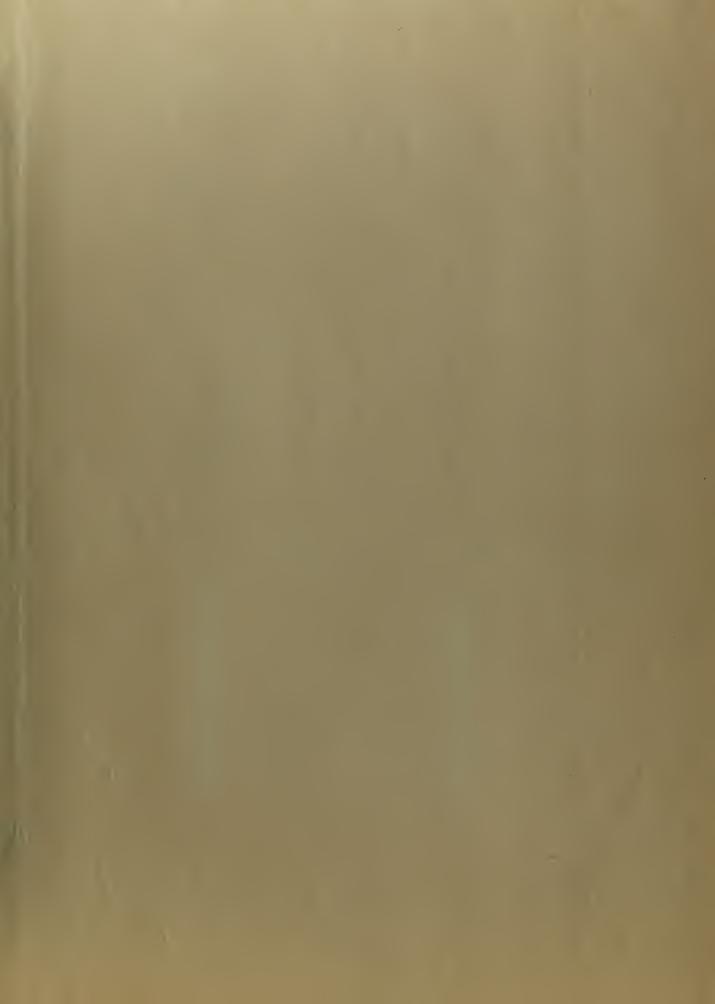
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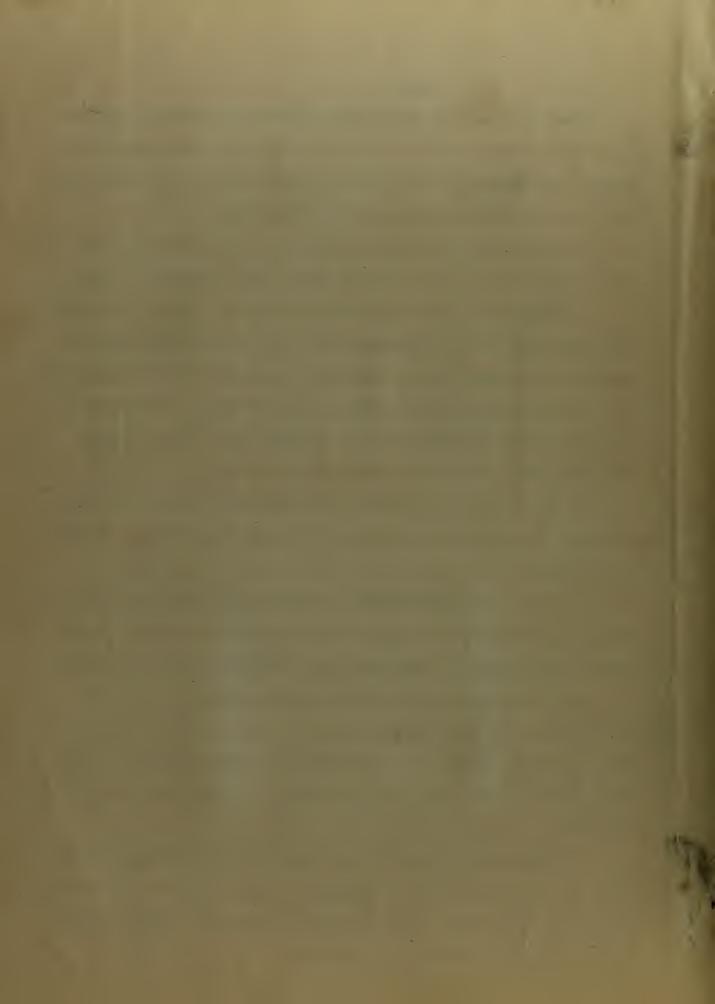
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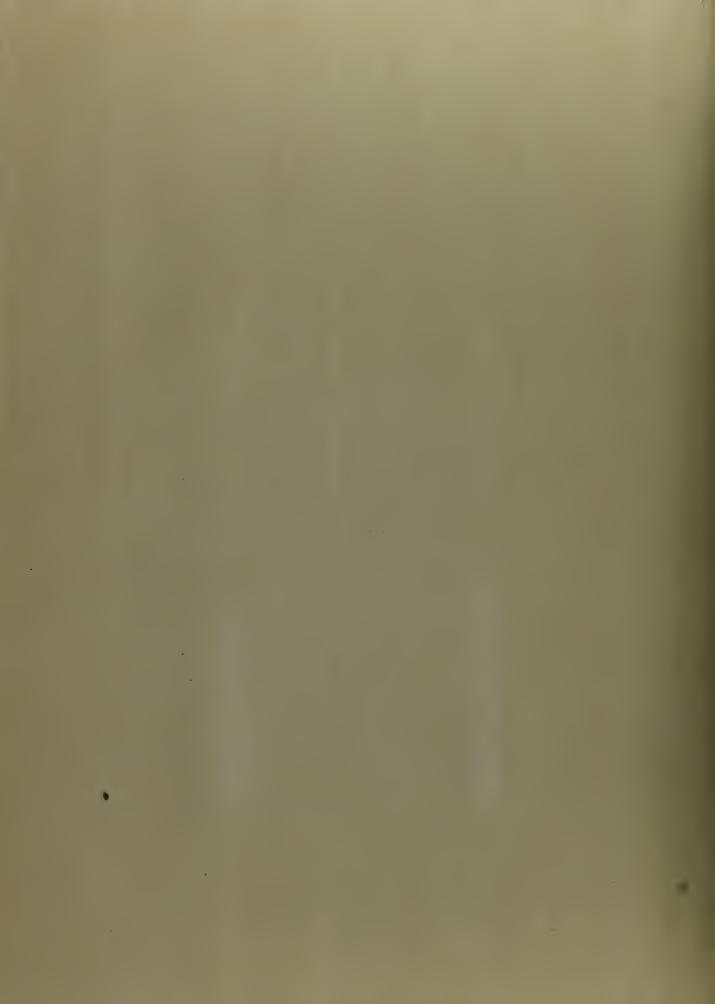
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Thunderstorm forecasting /

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